Restoration Plan
for the
Northwest Fork of the Loxahatchee River

South Florida Water Management District
Watershed Management Department
Coastal Ecosystems Division
Final Draft
Part 1
Executive Summary
Chapters 1 - 11
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EXECUTIVE SUMMARY

The unique ecosystem of the Northwest Fork of the Loxahatchee River, with its quiet beauty, has captured the attention and imagination of residents and visitors, agency and community leaders for many years. Consisting of 7.5 miles of federally-designated Wild and Scenic River, it provides essential habitats that support a wide spectrum of ecological resources including freshwater riverine floodplain vegetation (bald cypress), freshwater fish, tidal floodplain vegetation, saltwater fish, oysters and seagrasses. The natural pre-developed Loxahatchee Watershed was drained primarily by the Northwest Fork. However, the permanent opening of the Jupiter Inlet in 1947, along with sea level rise, has resulted in significant encroachment of a saltwater tolerant, mangrove-dominated community into the freshwater, bald cypress-dominated floodplain. Furthermore, the watershed has been permanently altered by the construction of canals for drainage. The C-18 Canal and S-46 Structure were constructed in the 1960s, which diverted the flows from the Northwest Fork to the Southwest Fork for flood control purposes. Now during the dry season, flows into the Northwest Fork do not retard the saltwater encroachment that causes damage to the freshwater floodplain ecosystem. Restoration and protection of the floodplain ecosystem depends largely on augmenting flows to the Northwest Fork at appropriate times, especially during the dry season.

In April 2003 the South Florida Water Management District (SFWMD) adopted a Minimum Flows and Levels Rule, Chapter 40E-8, Florida Administrative Code, with a minimum flow (MFL) for the Northwest Fork of the Loxahatchee River. As required by legislation, a Recovery Strategy was incorporated into the MFL Rule, which included a commitment by the SFWMD to develop, in partnership with the Florida Department of Environmental Protection (FDEP), “a practical Restoration Plan and goal” for the Northwest Fork of the Loxahatchee River. Therefore, the objective of the Northwest Fork Restoration Plan is to use the best available scientific and technical information to develop a practical restoration goal and plan to provide restorative flows to the ecosystem of the Northwest Fork of the Loxahatchee River.

Together the staff of the SFWMD, FDEP, Jonathan Dickinson State Park (JDSP), and the Loxahatchee River District (LRD) collected and analyzed the data used to develop and evaluate the restoration flow alternatives. After an analysis of historic and current flora and fauna communities, the Northwest Fork ecosystem was partitioned into the following five Valued Ecosystem Components (VECs):

1. Cypress swamp and hydric hammock in the freshwater riverine floodplain (River Mile [RM] 16 to RM 9.5),
2. Cypress swamp in the tidal floodplain (RM 9.5 to RM 5.5),
3. Fish larvae in the low salinity zone (RM 9.5 to RM 5.5),
4. Oysters in the mesohaline zone (RM 6.0 to RM 4.0) and,
5. Seagrasses in the polyhaline zone downstream (RM 4.0 to RM 0.0).

The health of these VECs is assumed to reflect the health of the ecosystem. Performance Measures for each VEC were developed to relate flow and stage in the floodplain and salinity in the river, to the ecological health of the VECs. These quantifiable PMs were used to evaluate the relative biological affects of each restoration flow alternative. The biological affects were evaluated in terms of protecting and, if possible, enhancing the freshwater floodplain ecosystem, increasing freshwater vegetation in the tidal floodplain while minimizing impacts on estuarine biota.

Formulation and evaluation of restoration alternatives were based on the successful application of hydrologic and salinity models developed for this project. These models include:

1. A watershed hydrologic model (WaSh) that simulates long-term freshwater inflows of tributaries to the Northwest Fork,
2. A 2-D estuarine, hydrodynamic and salinity model (RMA) that simulates short-term influences of these inflows and tide on estuarine salinity, and
3. A long-term salinity management model (LSMM) developed from RMA results, capable of predicting daily salinity in the estuary for the period of record used in the watershed model.

The present land use and drainage infrastructure for the watershed was used to simulate a base condition of daily freshwater flows for 39 years (1965 to 2003). This period of record ensured that modeled simulations for the plan contained a wide range of hydrologic conditions. In addition to the base case, a total of nine alternative flow scenarios were prepared. A relationship between flows and water stages was established to determine the frequency and magnitude of inundation in the freshwater riverine floodplain for the period of record. This information was used to evaluate biological affects of alternative flows on the freshwater riverine floodplain VEC while the modeled daily salinities provided input to assess impacts on the tidal floodplain and estuarine VECs. Alternative scenarios were compared to the base condition and other alternatives to identify the relative biological change among simulations. This assessment is critical in selecting a preferred restoration alternative because although one ecological component may be protected or restored, another component may be negatively impacted. This analysis of multiple ecological components allows the balance of affects to drive the selection of the preferred restoration flow alternative.

The first set of alternative flow scenarios represented five constant low flow targets during the 39-year period of record. These scenarios included constant flows of 65 cfs, 90 cfs, or 200 cfs over the Lainhart Dam coupled with 30 cfs, 65 cfs, 110 cfs, or 200 cfs in flows from the other tributaries of Cypress Creek, Hobe Grove Ditch and Kitching Creek. The ecological evaluations of the five constant flow scenarios indicated a few of the scenarios achieved some of the restoration goals; however, the overall ecological goals were not being fully achieved. Furthermore, a constant flow of 200 cfs over the Lainhart Dam during the dry season was considered to be harmful to the freshwater riverine floodplain and estuarine biota.

In response to the findings from the constant flow scenarios and public reaction to the results of the first five scenarios gained through a series of public meetings, three variable flow scenarios were developed to simulate a more natural, hydrological variability to achieve the restoration goal. Each variable flow scenario represented the Lainhart Dam flows with varying amount of augmented flows (mostly 65 cfs to 90 cfs during the dry season), added to which were three variable flows from the downstream tributaries, 60 cfs, 90 cfs and 120 cfs. After evaluating the ability of each variable flow scenario to achieve the restoration goal, the Preferred Restoration Flow Scenario was selected. This Preferred Scenario incorporates both dry and wet season hydrologic flow patterns and provides the greatest ecological benefit to freshwater riverine and tidal floodplain VECs with minimal impact on the estuarine VECs. In this scenario, variable flow from Lainhart Dam includes both seasonal and short-term variability (daily and monthly). Supplemental flows are introduced during the wet season to achieve 120 days of inundation of the cypress swamp/ freshwater riverine floodplain. In the dry season, supplemental flows maintain a mean monthly flow of 65 cfs to 90 cfs for freshwater riverine floodplain hydration and limit saltwater intrusion to the downstream segments. On a daily basis, these flows emulate pulses of water from small rain events and benefit estuarine plankton communities. Supplemental flows from the remaining tributaries of 30 cfs are simulated when the total flow to the Northwest Fork is less than 300 cfs.

The Preferred Restoration Flow Scenario provides near optimal inundation for the freshwater riverine floodplain forest, reverses saltwater intrusion within the tidal floodplain, and has minimal impact on the downstream estuarine biota. The Preferred Restoration Flow Scenario provides close approximations of optimal wet and dry season hydroperiods for cypress swamp in the freshwater riverine floodplain located between RM 16 and RM 9.5. In the freshwater riverine floodplain, the cypress swamp will be inundated for 4 to 8 months and the hydric hammocks will be inundated for about 30 to 60 days in a year. During the dry season, water levels in the freshwater riverine swamp will drop and allow cypress seed germination. In the tidal floodplain, between RM 9.5 and RM 5.5, flows will push the saltwater front downstream from RM 9.5 to between RM 8 and RM 7.5. This will allow for recruitment of freshwater species in the upper tidal floodplain. Freshwater species will be expected to expand in number and dominate the canopy to the mouth of Kitching Creek near RM 8. There will also be recruitment of pond apple in the tidal floodplain due to the improvement in the freshwater environment near RM 7.5.

The Preferred Restoration Flow Scenario is also designed to minimize the impact on the estuarine ecosystems. The low salinity zone, located between RM 9.5 and RM 5.5, requires a salinity regime of 2 ppt - 8 ppt during the dry season to function as a nursery for many saltwater fishes. Although restorative flows will move the appropriate salinity range downstream, the low salinity will still remain within an area that will provide suitable habitat for juvenile fish development. The optimal salinity range for oysters is from 10 ppt to 20 ppt, which is currently located between RM 6 and RM 4. With increased flows during the dry season these salinity levels will be moved downstream and the upstream oyster beds at RM 6 will be lost. However, the majority of the oysters are located downstream of RM 5 and will not experience harmful drops in salinity levels. The addition of oyster substrate near RM 4 will mitigate the loss of oysters at RM 6. The Preferred Restoration Flow Scenario will have minimal impact on seagrasses in the Central Embayment area.

The response of the biological communities to the effects of the Preferred Restoration Flow Scenario needs to be scientifically monitored to guide adaptive management decisions. The Restoration Plan supports existing monitoring activities and proposes new activities and programs necessary to monitor the water quantity, water quality, timing and distribution of increased dry season flows and improved wet season flows. In addition to existing vegetation monitoring programs, new monitoring programs for fish and wildlife data are proposed. A science plan to clearly identify and justify specific monitoring programs, scientifically based projects and special studies necessary to allow a comprehensive adaptive management plan to evolve is also proposed. The information collected from these monitoring programs and special projects will be used to update the restoration plan every five years from the date of adoption.

The Northwest Fork of the Loxahatchee River Restoration Plan with its Preferred Restoration Flow Scenario is the foundation for other important plans and projects within the Loxahatchee River Watershed. These include:

- Initial and Project Water Reservations for the Northwest Fork of the Loxahatchee River,
- Implementation of the North Palm Beach County CERP Project, Part I elements,
- Construction of additional water management/control structures,
- Development and implementation of operational protocols,
- Implementation of the Unit Plan for JDSP,
- Loxahatchee River Watershed Action Plan (DEP) project implementation,

- Loxahatchee River Preservation Initiative (LRPI), and
- Loxahatchee River National Wild and Scenic River Management Plan project implementation.

The SFWMD has the responsibility to implement water reservations and operational protocols for the regional water management structures. Community participation will ensure that the resource is protected. This plan was developed through interagency participation and cooperation, which is essential to successful restoration of the Northwest Fork. Implementation of the projects identified in the plan document and listed above by the SFWMD, FDEP, JDSP, LRD, USACE, local governments and community action will restore, preserve and protect the irreplaceable natural resources of the Northwest Fork of the Loxahatchee River for today and for the future.

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PURPOSE OF THE PLAN

The unique ecosystem and quiet beauty of the Northwest Fork of the Loxahatchee River has captured the attention and imagination of residents and visitors, agency and community leaders for many years. Efforts at all levels of government to preserve this ecosystem have lead to public ownership and management. The Loxahatchee River is generally referred to as the "last free flowing river in Southeast Florida" and represents one of the last vestiges of native cypress river swamp within southeast Florida. In May 1985, 9.5 miles of the Northwest Fork was federally designated as Florida's first National Wild and Scenic River. Portions of the river and estuary were designated Aquatic Preserves, Outstanding Florida Waters and Jonathan Dickinson State Park State (JDSP). Large sections of the river's watershed and river corridor are included within JDSP, which includes outstanding examples of the region's natural biological communities.

In recent history, adverse environmental impacts to this ecosystem have occurred due to alterations in watershed hydrology and sea level rise. The most widely recognized alteration is the reduction of dry season flows to the Northwest Fork and associated saltwater intrusion into freshwater wetland vegetation communities downstream. Most of the surface water runoff from the Loxahatchee River Watershed historically drained through Loxahatchee and Hungryland Sloughs to the Northwest Fork where tidal interaction was limited **(Figure 1-1).** However, today the C-18 Canal diverts much of the runoff from the Northwest Fork to the Southwest Fork of the river. Over the last century canals and levees were constructed to provide drainage and flood protection for development. Construction of numerous small drainage canals in the early part of the Twentieth Century and the C-18 Canal in 1958 diverted freshwater flows to tidal waters of the Southwest Fork at Structure S-46. In addition, prior to the 1940s, Jupiter Inlet periodically opened and closed to the Atlantic Ocean as a result of natural storm events. Since 1947 the inlet has been kept permanently open, and is presently maintained by periodic dredging conducted by the Jupiter Inlet District (USACE 1966). The permanent opening of the Jupiter Inlet has had a significant impact on the primarily freshwater system of the Northwest Fork through saltwater intrusion. During the past 58 years the vegetation along the river corridor in the Northwest Fork has changed from freshwater floodplain swamp to mangrove forest due to the saltwater intrusion from Jupiter Inlet and the reduced freshwater flows to the Northwest Fork.

In response to identification of these problems, remedial actions by many agencies, state and local, have influenced the management of flows to the Northwest Fork of Loxahatchee River. In 1982, a lawsuit was filed by the Florida Wildlife Federation (FWF; **Appendix F**) concerning the detrimental effects of the C-18 diversion. As a result, the South Florida Water Management District (SFWMD) and the Florida Department of the Environmental Protection (FDEP) entered into a Consent Decree to provide 50 cfs to the Northwest Fork "subject to the presence of available water supplies." The SFWMD constructed the G-92 water control structure to reestablish the flow linkage of the Loxahatchee Slough, through C-18, to the Northwest Fork. In addition, a 1989 agreement between the South Indian River Water Control District, the SFWMD and the Loxahatchee River Environmental Control District (LRD) provided operational guidelines for 400 cfs flows through G-92 to the Northwest Fork when feasible and allowing flood waters to backflow to the C-18 under certain conditions (**Appendix G**).

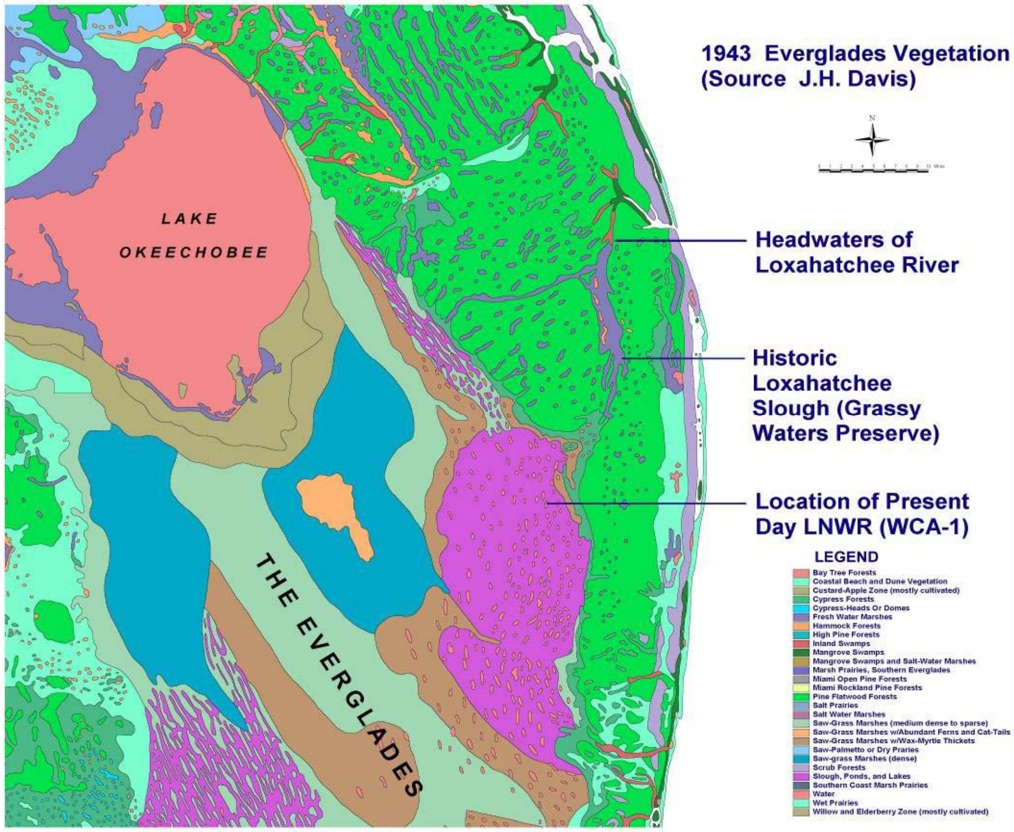

Figure 1-1. 1943 Vegetation Map of the Loxahatchee River Watershed. Source: Davis (1943) Vegetation Map of Southern Florida, Florida Geological Survey Bulletin 25, Figure 71.

In April 2003 the SFWMD adopted Minimum Flows and Levels Rule, Chapter 40E-8, F.A.C. with a minimum flow (MFL) for the Northwest Fork of the Loxahatchee River. It was recognized that upon adoption, the SFWMD would be unable to meet the MFL criteria during dry periods. Therefore, as required by legislation, a Recovery Strategy was incorporated into the Rule, which included a commitment by the SFWMD to develop a practical Restoration Plan and goal for this tributary in partnership with the FDEP.

The purpose of this plan is to 1) identify restoration alternatives, 2) document data collection and analysis conducted, 3) identify models and other analytical methods used in the development of the plan, and 4) describe the constraints and assumptions of the plan made by staff of the SFWMD, the FDEP and JDSP. The plan will address the environmental stresses the Northwest Fork ecosystems are currently facing, describe the constraints of the existing water management system, and explain the evaluation of restoration alternatives. It will provide the best available technical information to support environmentally sensitive dry and wet season flows or hydrographs for the ecosystems. A careful balance of the timing and distribution of flows will be provided.

Protection of the Northwest Fork ecosystems requires reducing or reversing the saltwater intrusion and subsequent environmental impacts on upstream freshwater wetland communities of vegetation and wildlife (e.g. fishes, alligators, turtles and otters). This major objective will be accomplished with minimum environmental impact on estuarine communities and their functions.

GENERAL DESCRIPTION AND GEOGRAPHIC LOCATION

The Loxahatchee River and Estuary are located along the Lower East Coast of Florida. This watershed drains an area of approximately 210 square miles within northern Palm Beach and southern Martin Counties and connects to the Atlantic Ocean via the Jupiter Inlet, in Jupiter, Florida. Just west of the inlet, the river opens into a Central Embayment area, which is formed at the confluence of three major tributaries – the Northwest Fork, the North Fork and the Southwest Fork (**Figure 1-2**).

The Northwest Fork of the Loxahatchee River originates at the G-92 Structure in northern Palm Beach County, flows north into Martin County and bends east through JDSP. Flows continue southeast back to Palm Beach County, near the Central Embayment area of the Loxahatchee River.

In 1985, the Loxahatchee River National Wild and Scenic Management Plan (FDNR 1985) established the Wild and Scenic designation of the Northwest Fork to be 7.5 miles in length, beginning at Boy Scout Dock (River Mile 6.0) and ending at Riverbend Park (RM 13.5). Using the measurement techniques available at the time, the river was measured from Jupiter Inlet to Riverbend Park and found to be 13 miles in length. In 2003, the SFWMD used Global Positioning System (GPS) technology to map the river more accurately, delineating its numerous oxbows, twists and turns. The recalculated length of the river from Jupiter Inlet to Riverbend Park is 15.5 miles and the “Wild and Scenic” portion of the river has been established as 9.5 miles in length. **Table 1-1** shows landmark sites of the Northwest Fork of the Loxahatchee River with the old River Miles used in existing documents (when applicable) and the new River Miles used throughout this document. (Note: The new River Miles are also used in the MFL Rule documents, Chapter 40E-8, F.A.C.)

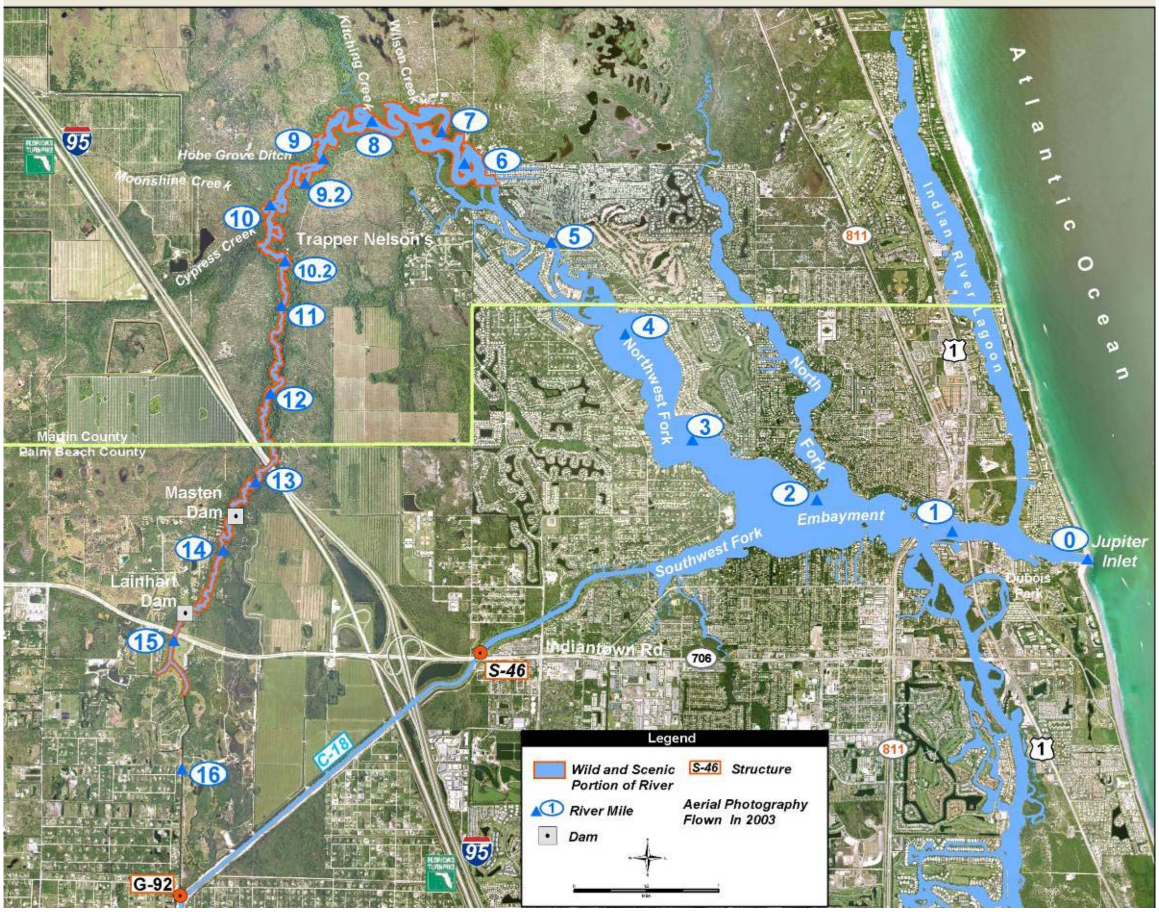

Figure 1-2. The Loxahatchee River and its Tributaries. The River Miles depicted on this map are based on the 2003 GPS and GIS analyses for the Northwest Fork.

Table 1-1. The River Mile Locations of Landmark Sites on the Northwest Fork of the Loxahatchee River.

Landmark Site	Old River Miles	New River Miles
Boy Scout Dock	6.00	5.90
Kitching Creek – USGS Monitoring Station	8.02	8.13
Hobe Grove Ditch	--	9.07
USGS Monitoring Station	--	9.12
Moonshine Creek	--	10.00
Cypress Creek	10.00	10.33
Trapper Nelson's	10.80	10.50
Turnpike/I-95	--	12.76
Masten Dam	--	13.50
Lainhart Dam	12.50	14.78
Indiantown Road	12.80	14.93
Riverbend Park	13.50	15.43

PARTNERSHIP WITH JONATHAN DICKINSON STATE PARK AND THE FLORIDA DEPARTMENT OF ENVIRONMENTAL PROTECTION

The FDEP has statutory responsibility and authority, Chapter 258.037, Florida Statutes, to "conserve these natural values for all time." Chapter 373.016, Florida Statues, authorizes the SFWMD to "to preserve natural resources…." Toward the development of the restoration plan for the Northwest Fork of the Loxahatchee River, the Florida Department of Environmental Protection, which includes the Florida Park Service, and Jonathan Dickinson State Park, has actively engaged in a partnership with the SFMWD to conduct research and examine technical issues surrounding restoration. Much of this plan is based on that partnership.

On April 22, 2004, a meeting attended by staff representatives from FDEP, JDSP and SFWMD was held to discuss the guiding principles for the development of a practical restoration goal and plan for the Northwest Fork of the Loxahatchee River. Those in attendance at the meeting agreed on the following principles:

- Restoration of the Northwest Fork of the Loxahatchee River will occur between River Mile 6.0 and River Mile 15.5 to the extent practicable.
- A "practical" and "achievable" restoration goal for the Northwest Fork of the Loxahatchee River will be based on best available data.
- One part of the Loxahatchee River Watershed will not be sacrificed to benefit another part of the Watershed. This principle also applies to areas of the river within the "Wild and Scenic" portion of the Northwest Fork.
- The Restoration Goal and Plan for the Northwest Fork of the Loxahatchee River will balance water supply, flood protection, water quality and environmental enhancement.
- The Restoration Goal and Plan for the Northwest Fork of the Loxahatchee River will be based on a seasonal hydrograph.
- To the extent practicable, ecological benefits will be maximized system wide.
- The focus of the goal and plan will be the restoration of the Northwest Fork of the Loxahatchee River; therefore, the title of the goal and plan will reflect that emphasis.

In addition, it was agreed that the estuarine area of the Loxahatchee River, which is located from RM 2.0 to RM 6.0, will be protected or improved through reductions of high freshwater flows, when possible, from S-46 to the Southwest Fork of the Loxahatchee River.

PLANS AND IMPLEMENTATION ACTIVITIES

During the past 20 years several plans and restoration-oriented activities have been initiated to protect and restore the Loxahatchee River, especially the Northwest Fork:

Loxahatchee River National Wild and Scenic River Management Plan

In May 1985, the largely pristine portion of the Northwest Fork of the Loxahatchee River was designated by the U.S. Department of the Interior for inclusion in the Federal Wild and Scenic Rivers System, following designation by the state of Florida as a Wild and Scenic River in 1983 (Chapter 83-358, Laws of Florida, approved June 1983). The Northwest Fork of the Loxahatchee River was the first river in the state of Florida to receive this designation.

An outcome of the state and federal government actions was the formation of the Loxahatchee River Management Coordinating Council. Comprised of regional, state, federal agency and local government representatives, it oversees the impacts of proposed development, tracks plans and programs in areas adjacent to the Northwest Fork and its corridor, and is responsible for the development of a management plan.

Written by the FDEP and the SFWMD, The *Loxahatchee National Wild and Scenic River Management Plan* (2000) ensures that special consideration be given to the watershed surrounding the river corridor so that it is protected to maintain natural flow conditions, good water quality and the preservation of high quality natural areas. The plan is updated every five years to track the successful accomplishments of the member agencies and local governments and to identify new projects and programs, all of which are necessary for the protection and restoration of the Northwest Fork.

Lower East Coast Regional Water Supply Plan

In May 2000, the Governing Board of the South Florida Water Management District adopted the Lower East Coast Regional Water Supply Plan (LEC Plan). The purpose of the LEC Plan is to fulfill the requirements of Section 373.0361, Florida Statutes (F.S.) for regional water supply plans. Implementation of the LEC Plan will do the following:

- Create a water supply that fully meets the future (2020) needs of almost seven million people, agriculture and industries during a 1-in-10 year drought.
- Reduce the number of severe violations of Minimum Flow and Levels (MFL) criteria for the Everglades, Lake Okeechobee and the Biscayne aquifer by 2020.
- Reserve from allocations sufficient water to allow for the restoration of the Everglades and enhancement of other significant natural systems.
- Reduce the uncertainty for issuing long-term permits for water users as they invest in tomorrow's water supply infrastructure.
- Provide public forums to modernize District operational procedures and promote greater flexibility in the operation of the regional water management system.

Several LEC Plan recommendations also provide the foundation for various actions to protect and restore the Northwest Fork of the Loxahatchee River:

LEC Recommendation 3:	Northern Palm Beach County Comprehensive Water Management Plan
LEC Recommendation 21:	L-8 Project
LEC Recommendation 32:	Periodic Operational Flexibility
LEC Recommendation 34:	Water Reservations
LEC Recommendation 35:	Establish MFLs

Water Supply Plans are updated every five years, and an update to the LEC Plan is underway, with a completion date of December 2005.

Northern Palm Beach County Comprehensive Water Management Plan

Initiated in 1995, the Northern Palm Beach County Comprehensive Water Management Plan (Northern Plan) was accepted by the SFWMD Governing Board in May 2002 (SFWMD 2002a).

The sub-regional Northern Plan focuses on the southern L-8 Basin, the City of West Palm Beach Water Catchment Area (WCA-1) or Grassy Waters Preserve, C-18, the Loxahatchee Slough, and the Loxahatchee River, especially the Northwest Fork. The plan projects future water supplies for urban, agricultural and environmental uses for the year 2020 and identifies projects that when built will bring supplemental water into the northern Palm Beach County area.

The Northern Plan calls for a series of system improvements to be constructed in the area of Palm Beach County north of Southern Boulevard, generally east of the L-8 Levee, and west of I-95. When all the proposed system improvements are in place, the Northern Plan will provide the projected 2020 public water supply demands of the area, hydrologic restoration of the Loxahatchee Slough, and protection of the Grassy Waters Preserve and a target base flow of 65 cubic feet per second (cfs), in the dry season, to the Northwest Fork of the Loxahatchee River, measured at the Lainhart Dam. Construction has started on several of the Northern Plan components: the Loxahatchee Slough structure (G-160) was completed in January 2004; design of the Northlake Boulevard structure (G-161) was initiated in 2004 with construction expected to be completed in 2005; and, the regional reservoir storage at the Palm Beach Aggregates site was increased to 47,000 acre-feet in 2004. The Northern Plan forms the basis for the North Palm Beach County CERP Project, Part 1.

North Palm Beach County CERP Project – Part 1

The overall purpose of the North Palm Beach County CERP Project – Part 1 is to:

(1) increase water supplies to the Grassy Waters Preserve and Loxahatchee Slough;

(2) provide flows to enhance hydroperiods in the Loxahatchee Slough;

(3) increase base flows to the Northwest Fork of the Loxahatchee River; and

(4) reduce high flows to the Lake Worth Lagoon and Loxahatchee Estuary.

The North Palm Beach County CERP Project includes six individual elements including Pal-Mar and J.W. Corbett Wildlife Management Area Hydropattern Restoration, L-8 Basin Modifications, C-51 and L-8 Reservoir, Lake Worth Lagoon Restoration, C-17 Pumping and Treatment, and C-51 Pumping and Treatment. These elements have been combined into a single project to address the interdependencies and tradeoffs between the different elements and provide a more efficient and effective design of the overall project. Further details on this project are presented on the District's Website at http://www.evergladesplan.org.

Minimum Flows and Levels Rule, Chapter 40E-8, F.A.C.

Minimum Flows and Levels criteria for the Northwest Fork of the Loxahatchee River (SFWMD 2002b) were developed to protect the remaining floodplain swamp community and downstream estuarine resources from "significant harm." Adopted in April 2003, the minimum flow is defined as "The limit at which further withdrawals would be significantly harmful to water resources or ecology of the area..."

More specifically, the criteria for the determination of an MFL violation are as follows:

A MFL violation occurs within the Northwest Fork of the Loxahatchee River when an exceedance of the minimum flow criteria occurs more than once every six years. An "exceedance" is defined as when Lainhart Dam flows to the Northwest Fork of the river decline below 35 cubic feet per second for more than 20 consecutive days within any given calendar year.

It was recognized that upon adoption, the District would be unable to meet the MFL criteria for the Northwest Fork during dry periods. Therefore, as required by legislation, a Recovery Strategy was incorporated into the Rule, which includes the following:

1. Construction of projects which will increase flows to the Northwest Fork and which are identified in the *Lower East Coast Regional Water Supply Plan*, the North Palm Beach County CERP Project, Part 1 and the *Northern Palm Beach County Comprehensive Water Management Plan* projects,
2. In partnership with the Florida Department of Environmental Protection and Jonathan Dickinson State Park, continue the development of a practical Restoration Plan and goal for the Northwest Fork of the Loxahatchee River,
3. Adoption of an initial water Reservation for the Northwest Fork of the Loxahatchee River to protect existing water used for the protection of fish and wildlife, and subsequent reservations to protect water made available for the recovery and restoration of the Loxahatchee River through implementation of projects which will increase flows in the dry season. These water reservations are intended to prevent the future allocation to consumptive uses the freshwater intended for restoration of the Northwest Fork of the Loxahatchee River,
4. Continue to operate the G-92 Structure and associated structures to provide flows of approximately 50 cfs or more over Lainhart Dam to the Northwest Fork, when the District determines that water supplies are available, and
5. It is the intent of the District to continue the current operational protocols of the G-92 Structure so as not to reduce the historical high, average and low flows as estimated over the 30-year period of rainfall record used as the basis for the MFL for the Northwest Fork of the Loxahatchee River.

Loxahatchee River Watershed Action Plan

In July 1996, the Florida Department of Environmental Protection organized the Loxahatchee River Watershed Planning Committee with representatives from various state, local and federal agencies. A Loxahatchee River Watershed map was developed and through the development of the watershed boundaries, a comprehensive list of problems could be identified for each subbasin. In addition, water quality data and other environmental information were compiled to form a realistic view of the watershed. In October 2002 the Loxahatchee River Watershed Action Plan was completed (FDEP 2002). The purpose of this plan was to identify natural resource problems within the watershed subbasins and solutions for those problems. One of the more successful results of the Loxahatchee River Watershed Action Plan is the Loxahatchee River Preservation Initiative (LRPI), which has succeeded in gaining state appropriations for projects that contribute to the restoration and protection of the Loxahatchee River and Watershed.

Loxahatchee River Preservation Initiative

The Loxahatchee River Preservation Initiative (LRPI) is the outgrowth of the Loxahatchee River Watershed Action Plan. In the past, several key projects crucial to preserving the long-term health of the Loxahatchee River could not be implemented due to lack of resources and other regional priorities taking precedence. To address this problem, the LRPI was formed in 2000 with the single purpose of seeking funds for projects that would improve and protect the natural resources within the watershed. The LRPI has been successful in obtaining approximately six million dollars for projects. Urban stormwater improvements and the restoration of tributaries to the Loxahatchee, including the estuarine portion of the river system, are projects emphasized by the LRPI.

Jonathan Dickinson State Park Unit Management Plan

This plan serves as a basic statement of policy and direction of JDSP as a unit of Florida's State Park System (FDEP 2000). It identifies the objectives, criteria and standards that guide each aspect of park administration and sets forth specific measures that will be implemented to meet management objectives. The plan is divided into three interrelated components: resource management, land use and operations. Park goals and objectives include preserving the park's natural resources, creating awareness and appreciation for the park, enhancing organized programs and increasing attendance and visitation.

The park consists of approximately 11,383 acres in Martin County and northern Palm Beach County. Within the park, 2,600 acres comprise a wilderness preserve and 2,100 acres consist of the highly endangered scrub community. Twelve natural communities occur within the unit, including six wetland communities. The park also contains part of the National Wild and Scenic Northwest Fork of the Loxahatchee River. These rare natural features create an exceptional environment for plants and wildlife including many designated species.

Jupiter Inlet District Management Plan for the Loxahatchee River

This plan is intended to continue public recreational uses, improve the productivity of the river, and preserve and enhance the natural resources and multiple uses of the Loxahatchee River for which JID has authority (JID 1993). The plan addresses the portion of the Loxahatchee River west of the F.E.C. Railroad trestle including the Central Embayment, North Fork, Northwest Fork, Southwest Fork, C-18 Canal, and minor tributaries. Thirty prioritized options were included in the plan. One of the specific actions that has been taken is the restoration of four oxbows in the Northwest Fork to preserve natural hydrological functions.

DOCUMENT STRUCTURE

There are eleven chapters in the plan document. The next section of the document is **Chapter 2**, **The Loxahatchee River Watershed**; which describes the Loxahatchee River and its tributaries, the Loxahatchee estuary, and the surrounding land areas. The watershed is divided into 12 drainage basins based on hydrology and land use. Water quality and water resource utilization of the watershed are also described.

Chapter 3, **The Ecosystems of the Loxahatchee River and Estuary**, describes the floodplain and estuarine ecosystems of the Northwest Fork of the Loxahatchee River. The historic and present day distributions of species in the floodplain forest communities and oligohaline, mesohaline, and polyhaline ecozones are also presented. The occurrence of endangered, threatened or species of special concern are included in the ecosystem descriptions.

Chapter 4, Valued Ecosystem Components (VECs) and Performance Measures (PMs), describes the Valued Ecosystem Components selected to represent the freshwater and tidal floodplain, and estuarine ecosystems. The Performance Measures used to assess the results of the restoration flow scenario evaluation process are also identified.

Chapter 5, Determining Hydroperiods and Flow Requirements in the Riverine Floodplain, describes habitat quality and floodplain hydrology evaluations.

Chapter 6, Modeling Freshwater Flow and Salinity in the Northwest Fork of the Loxahatchee River and Estuary, describes the watershed hydrology and the models used to predict long-term freshwater flow and salinity. Results from the model calibration, validation, and long-term simulations are presented. The freshwater flow and salinity relationships are summarized.

Chapter 7, The Northwest Fork Restoration Flow Scenarios: Initial Evaluation, describes the alternative constant flow scenarios formulated for modeling, the modeling results and the ecological assessment of the initial alternatives.

Chapter 8, **Development of the Preferred Restoration Flow Scenario for the Northwest Fork of the Loxahatchee River,** describes the variable flow scenarios analyzed to identify an effective restorative flow scenario that will protect the riverine freshwater floodplain, restore the tidal floodplain to the extent possible and protect the estuarine VECs of the Northwest Fork.

Chapter 9, **The Saltwater Barrier as a Restoration Alternative**, describes the 3-D salinity model used, the preliminary modeling study of salinity management using different types of salinity barriers, and the ecological considerations associated with saltwater barriers.

Chapter 10, Ecological Monitoring for Adaptive Management, identifies the vegetation and hydroperiod monitoring in the freshwater floodplain, vegetation and salinity monitoring in the tidal floodplain, benthos/fish larvae monitoring in the oligohaline ecozone, oyster monitoring in the mesohaline ecozone, and seagrass monitoring in the polyhaline ecozone necessary to evaluate the effects of restorative flows to the Northwest Fork.

Chapter 11, Restoration Implementation, identifies the programs such as CERP, the projects such as the L-8 Reservoir and regulatory efforts such as Water Reservations that will create and establish the means to achieve the flow targets for the Northwest Fork. Improved operations that will be required in the coming decades to achieve these restorative flows are also addressed.

SUMMARY

In summary, the overall purpose of the Northwest Fork of the Loxahatchee River Restoration Plan is to establish a combination of flows and other water management practices that will restore and protect the ecological health of the Northwest Fork of the Loxahatchee River. Development of a restorative dry season/wet season hydrologic flow pattern will:

- Maintain or improve the hydroperiod of the riverine floodplain,
- Increase the growth and recruitment of desired freshwater vegetation and control the expansion of mangroves and exotic species in the tidally influenced floodplain, and
- Minimize the impact on the habitats of estuarine biota in the Northwest Fork, Central Embayment Area and Estuary.

The improved wet season/dry season flows to the Northwest Fork over the Lainhart Dam and from its tributaries, Cypress Creek, Hobe Grove Ditch and Kitching Creek and other dry season measures are intended to protect the freshwater floodplain and improve the quality of the tidally influenced portion of the floodplain. This will maintain and protect vegetation, fish and wildlife values within the constraints of the influence of the Jupiter Inlet, sea level rise, and existing levels of flood control, C-18, G-92 and S-46. Current levels of navigation and recreation on the Northwest Fork of the Loxahatchee River will be maintained.

CHAPTER 2

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Chapter 2: The Watershed

GENERAL DESCRIPTION

The Loxahatchee River, Estuary and upstream watershed are located along the southeast coast of Florida at the southern end of the Indian River Lagoon. Historically, the Loxahatchee River Watershed drained roughly 270 square miles of sloughs and wetlands. Today, the watershed located within northern Palm Beach and southern Martin Counties drains an area of approximately 210 square miles and connects to the Atlantic Ocean through the Jupiter Inlet. Much of the watershed remains undeveloped. In the upper portion of the watershed, nearly half of the drainage basin is comprised of wetlands. Agriculture and forested uplands in the northern area of the basin comprise one quarter of the watershed. The remaining quarter of the watershed consists of developed urban areas.

The Loxahatchee Estuary's central embayment is located at the center of three major tributaries- the Northwest Fork, the North Fork and the Southwest Fork (**Figure 2-1**). The headwaters of the Loxahatchee River begin in the Grassy Waters Preserve and Loxahatchee Slough which drain north to the Northwest Fork. From the Loxahatchee Slough, water flows north in the C-18 Canal, through the G-92 Structure into the natural river stream of the Northwest Fork. It enters Martin County and JDSP and continues along a northerly course, then bends east and continues southeast through the central embayment of the Loxahatchee River. The North Fork headwater, defined by the Atlantic Coastal Ridge in eastern Martin County, flows south-southeast into the central embayment. In 1957, all but one mile of the Southwest Fork was channelized to form the C-18 Canal to move water flows to the northeast, providing flood control to northern Palm Beach County. While the majority of the water that feeds the Northwest Fork comes from northern Palm Beach County, water also flows to the Northwest Fork from southern Martin County, through Cypress Creek, Hobe Grove Ditch, Moonshine Creek and Kitching Creek

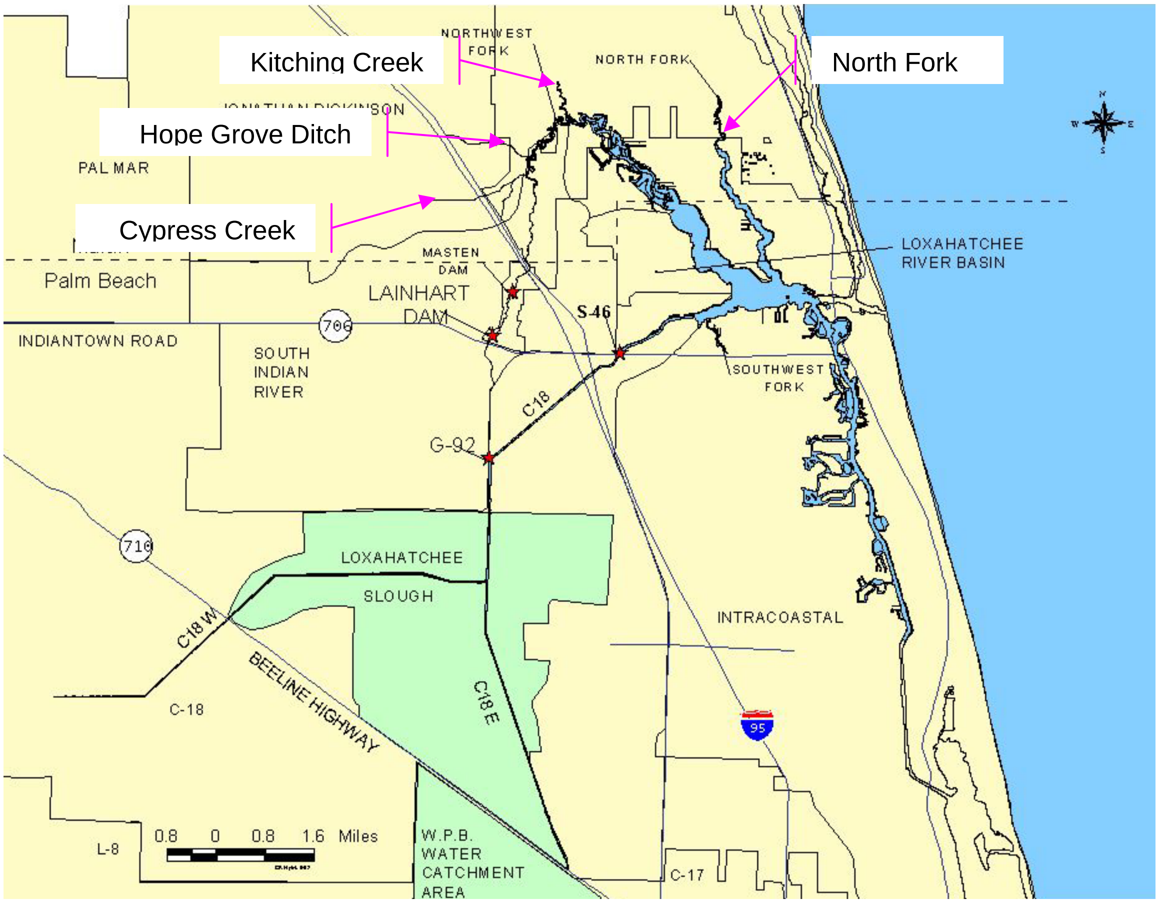

Figure 2-1. Location of the Loxahatchee River and major tributaries and water control structures in the watershed.

The Loxahatchee River watershed contains a number of natural areas that are essentially intact and publicly owned. These areas include the J.W. Corbett Wildlife Management Area, JDSP, Hungryland Slough Natural Area, Grassy Waters Preserve, Loxahatchee Slough, Hobe Sound National Wildlife Refuge, Juno Hills Natural Area, Jupiter Ridge Natural Area, Pal-Mar, Cypress Creek and the Atlantic Coastal Ridge. These natural areas contain pinelands, sand pine scrub, xeric oak scrub, hardwood hammock, freshwater marsh, wet prairie, cypress swamp, mangrove swamps, ponds, sloughs, river and streams, seagrass and oyster beds and coastal dunes. These areas support diverse biological communities, including many protected species (FDEP 1998). In addition, the watershed contains managed agricultural lands along with areas impacted by urban and suburban development.

SUBBASINS

Historically, the Loxahatchee River watershed drained 270 square miles of inland sloughs and wetlands. Some of the major tributary streams, such as the North Fork, the Northwest Fork and Kitching Creek exist today largely within their historic banks. Other creeks, such as the Southwest Fork, Limestone Creek and parts of Cypress Creek, have been altered over time. Today the watershed encompasses roughly 80 percent of its historic size (about 210 sq. miles) and more than half of the land still remains undeveloped with the remainder altered by agricultural or urban development. The undeveloped lands exist as wetlands and uplands. The watershed also contains about 4000 acres of open water, including lakes and the estuary (FDEP 1998).

Although the total area of the watershed has not changed dramatically, drainage patterns have been significantly altered with the building of roads (e.g., S.R. 710, I-95, and Florida Turnpike), construction of the C-18 and other associated water control structures, and the development of an extensive secondary canal network. Canals were designed to provide drainage and flood protection for agricultural and urban development and the conveyance of water for potable use and irrigation. Over time, drainage and development in the watershed have lowered ground water levels and altered natural flow regimes and drainage patterns.

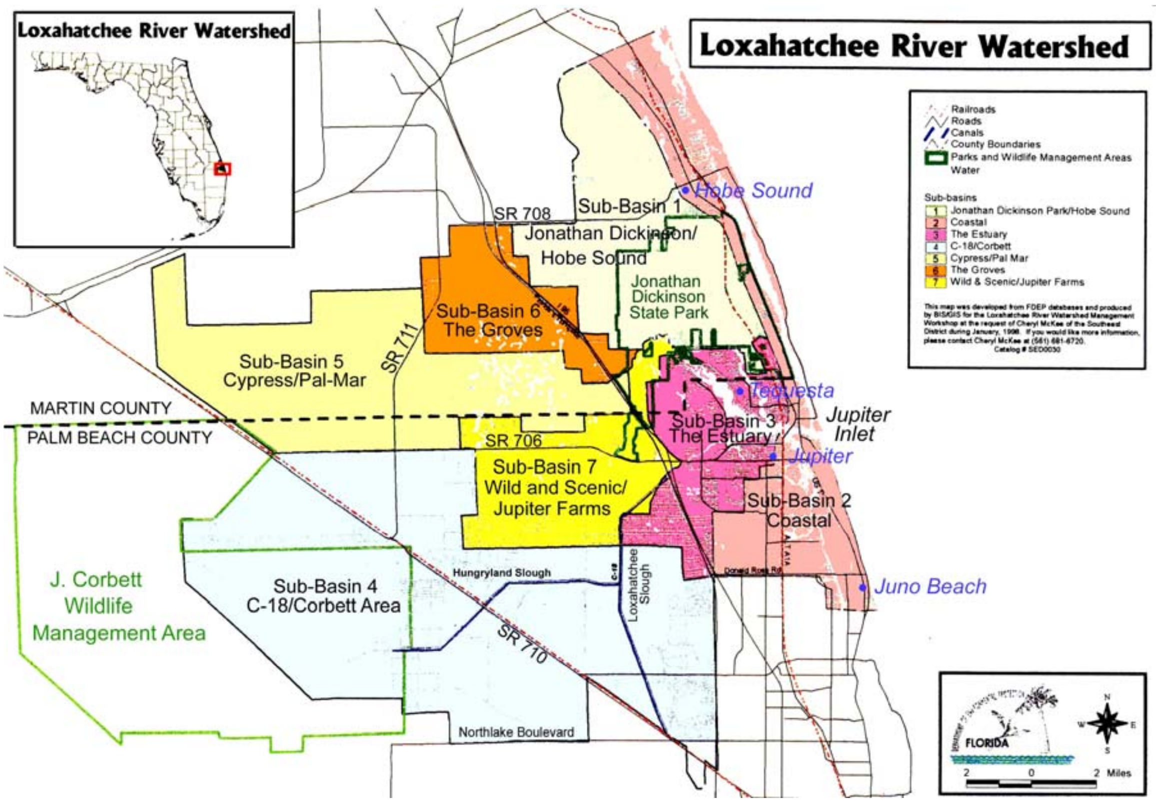

Figure 2-2. Major Drainage Basins in the Loxahatchee River Watershed (source: FDEP, 1998).

The watershed is a group of seven sub-basins, as defined by FDEP (1998). The subbasins vary in size from 17 to 100 square miles, and they provide runoff to the three forks of the Loxahatchee River (**Figure 2-2**). Sub-basin boundaries are based primarily on hydrology and secondarily on land use. Each of these sub-basins plays an important role in the watershed.

Subbasin 1: Jonathan Dickinson. Two parallel basins, the North Fork of the Loxahatchee and Kitching Creek make up the northeastern portion of the Loxahatchee River watershed. Over 40 percent of the 36 square miles of this subbasin are within the boundaries of JDSP, and contribute runoff from natural lands. A portion of surface and ground waters from this basin flows into the North Fork River. The remainder flows into Kitching Creek and discharges into the Northwest Fork near River Mile 8.2 (SFWMD 2004).

Subbasin 2: Coastal. The coastal subbasin consists of approximately 34 square miles of land that drains to the Intracoastal Waterway (ICW) and out the Jupiter Inlet. This subbasin has been developed for maximum urban residential, commercial and recreational use. Very few small and isolated natural areas remain. Most of the surface water and ground water from this subbasin discharge to marine waters rather than towards to the freshwater portion of the Northwest Fork (SFWMD 2004).

Subbasin 3: Estuary. This central drainage subbasin is highly developed with urban land uses that contribute significant runoff to the major central embayment of the Loxahatchee River. Consisting of over 21 square miles of the watershed, this subbasin provides aquatic recreational opportunities that sometimes exceed the river's carrying capacity on weekends and holidays. Runoff and groundwater from most of this subbasin discharge to brackish waters of the estuary (SFWMD 2004).

Subbasin 4: C-18/Corbett Wildlife Management Area (WMA). Over 100 square miles make this the largest subbasin in the watershed. Much of the land in this subbasin, encompasses the southwestern portion of the watershed, and is publicly owned and protected. This subbasin includes the remnants of the Hungryland and Loxahatchee Sloughs, which historically fed the Northwest Fork of the Loxahatchee River. At one time, the Loxahatchee Slough extended south into what is now known as the Grassy Waters Preserve (West Palm Beach Water Catchment Area), which is the source of drinking water for the City of West Palm Beach. Water from this subbasin discharges to the C-18 Canal, and is discharged to the Southwest Fork or directed through the G-92 Structure to the upper end of Northwest Fork of the Loxahatchee River (SFWMD 2004).

Subbasin 5: Cypress Creek/Pal-Mar. Cypress Creek, a large 46 square mile subbasin, drains a sizable wetland located in the western extremities of the watershed and is one of the major tributaries to the Loxahatchee River. Most of these wetlands remain intact, however the eastern flow ways leading to the creek have been disturbed by rural development. Water from this subbasin flows into Cypress Creek and discharges at the upper end of the Northwest Fork near River Mile 10 (SFWMD 2004).

Subbasin 6: Groves. Agricultural operations are found in four of the seven subbasins, and the predominant land use in this 17 square mile subbasin is primarily citrus. Although the hydrology in this subbasin was altered to support agriculture, wildlife utilization is good and the land provides a valuable greenway link between large natural areas within the watershed. Water from this sub-basin flows into Hobe Groves Ditch and discharges into the Northwest Fork near River Mile 9 (SFWMD 2004).

Subbasin 7: Wild and Scenic River/Jupiter Farms. This subbasin is over 23 square miles and is divided into a larger upstream section, which has been channelized and now supports substantial rural residential development (Jupiter Farms), and the downstream portion that comprises the "wild and scenic" Northwest Fork of the Loxahatchee River. Water quality in the Northwest Fork is a concern in this subbasin (FDEP 1998). Water from the upstream section of this subbasin discharges into the upper end of the Northwest Fork through the C-14 Canal, between the G-92 Structure and Lainhart Dam. The downstream section of this subbasin discharges directly from the C-18 Canal through G-92, and over the Lainhart Dam into the Northwest Fork (SFWMD 2004).

WATERSHED HYDROLOGY

CLIMATE, RAINFALL AND SEASONAL WEATHER PATTERNS

The subtropical regional climate for the area has daily temperatures ranging from an average of 82° F in summer (May - Oct.) to 66° F in winter (Nov. - Apr.) with an annual temperature of 75° F (Breedlove 1982). Prevailing marine east/southeast winds with an average velocity of approximately 10 miles per hour keeps the air within the watershed area moist and unstable, leading to frequent rain showers of short duration.

Annual rainfall amounts received within northern Palm Beach and southern Martin Counties are summarized in **Figure 2-3** and represent the years from 1914-2000 (data from South Florida Water Management Model, version 9.7). Mean annual rainfall for the entire 86-year period of record was 60.4 inches with a median of 57.7 inches. The maximum annual rainfall recorded was 92.9 inches in 1947 and 91.6 inches in 1994. Minimum rainfall values occurred in 1956 (38.4 inches) and 1961 (41 inches). Review of the distribution of annual rainfall data over time showed that a variance of about 10 percent of the mean (plus or minus 6 inches) occurs about once every 3 years on average. Extreme dry and wet periods can be defined as a variance of more than 20 percent of the mean (+ 12 inches). Based on this definition, the long-term record shows that an extreme dry period occurs within the basin once every 8.6 years, while extreme wet periods occur about once every 5.7 years.

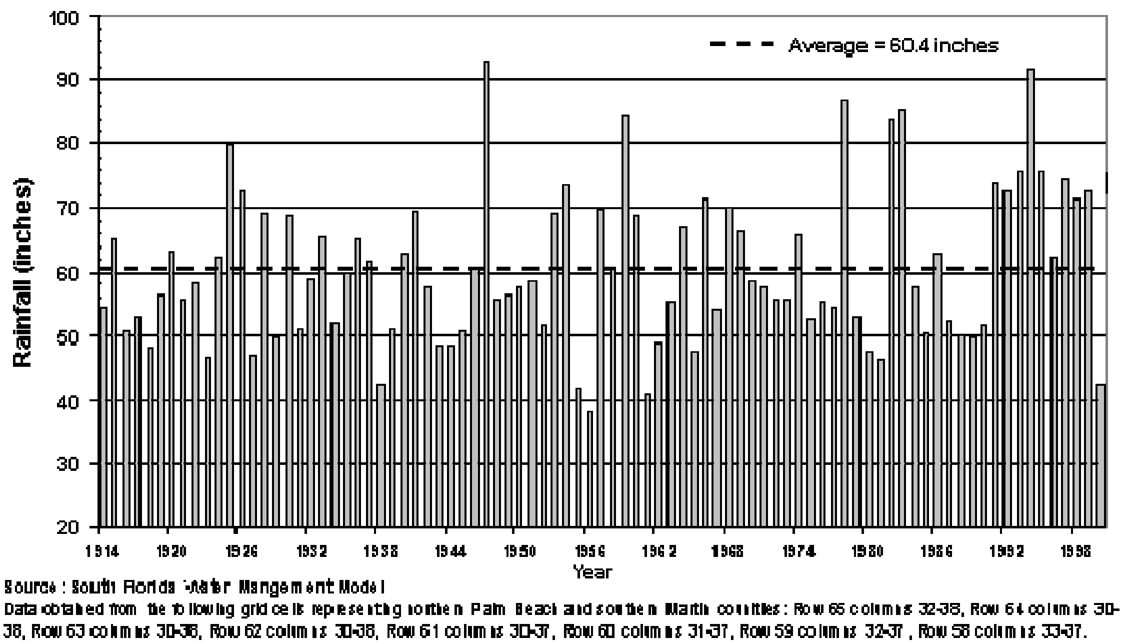

Figure 2-3. Long-term Annual Rainfall for Northern Palm Beach and Southern Martin Counties (1914–2000).

The average, minimum, and maximum monthly rainfall amounts for northern Palm Beach and southern Martin Counties for 1914-2000 are summarized in **Figure 2-4**. On average, the highest rainfall of 8.7 inches per month occurs during the month of September, while minimum average values range from 2.3 – 2.8 inches per month for the months of December, January and February. May and November are transitional months and sometimes represent key months for prolonging or reducing a drought or flood condition. Dent (1977a) reported that since the early 1960s, about two-thirds of this precipitation (40.63 inches) occurs during the wet season (May –

October), while the remaining one-third (20.42 inches) falls during the dry season (November – April). During the winter and early spring, some years have long periods of little or no rainfall, resulting in a regional drought condition. In contrast, tropical storms or hurricanes over the area can produce as much as 6 to 10 inches of rainfall in one day. Total annual rainfall can be as much as 93 inches or as low as 38 inches (**Figure 2-3**).

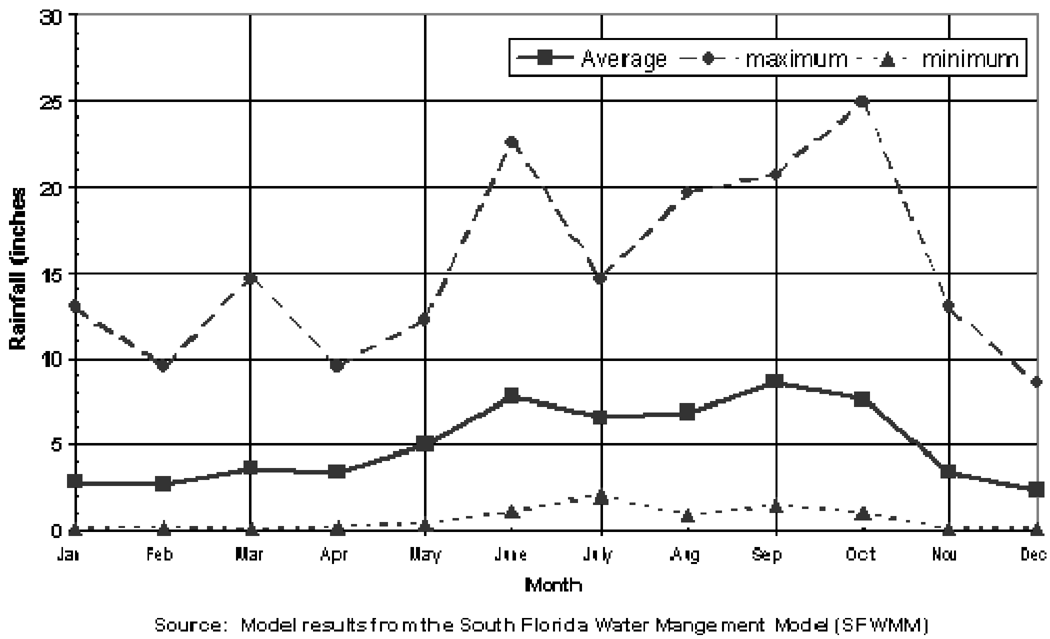

Figure 2-4. Average, Minimum and Maximum Rainfall Values, by Month, for Northern Palm Beach and Southern Martin Counties (1914–2000).

TRIBUTARY AND CANAL SYSTEM

The Northwest Fork once drained the majority of the Loxahatchee Basin. The headwaters to the river began in the marshes of the Loxahatchee and Hungryland Sloughs, and in what is now Grassy Waters Preserve (**Figure 2-1**). The Loxahatchee Slough extended south to the Grassy Waters Preserve (West Palm Beach Water Catchment Area). Increased urban and agricultural development over the last 100 years has greatly altered the natural system of the Loxahatchee watershed from what once was defined by natural landforms. Navigation, drainage and flood control activities have significantly altered the volume, timing and distribution of freshwater flow, both in quality and quantity, throughout the Loxahatchee River and Estuary system. According to the USGS the decrease in flow can be attributed to the diversion of the historic Northwest Fork flows by the construction of C-18 Canal. This area, once drained as sheet flow across flat landscape, has become divided by canals, levees and drainage ditches. Over time these changes have lowered the water table and have allowed the land to drain much faster. Reduced flows to the Northwest Fork have allowed saltwater to move further upstream.

The C-18 Canal drains a 106-square mile area and accounts for more than 50 percent of the river basin emptying into the Southwest Fork through a gated water control structure, S-46. In order to reduce the amount of freshwater lost to tide S-46 was modified in 1981 to provide water storage in the canal. The automated operation of the gates at S-46 maintains an optimum headwater elevation of 14.8 feet when sufficient water is available. When C-18 Canal levels are more than 15 feet above mean sea level, water is released through S-46 to the Southwest Fork. The S-46 Structure also prevents saline water from moving upstream beyond River Mile 4.8.

Water is conveyed from the Loxahatchee Slough north through the C-18, C-14, G-92 and the Lainhart Dam to the Northwest Fork of the Loxahatchee River. The diversion structure, G-92, was installed to move water back into the Northwest Fork from C-18. Updated in 1987 to a gated control structure, G-92 is capable of providing 400 cfs of water to the Northwest Fork. Operation of this structure is by remote telemetry under a joint agreement between the SFWMD and the South Indian River Water Control District to allow conveyance of environmental flows to the Northwest Fork. During extremely wet storm events, G-92 moves excess water into the C-18 for flood protection. A Consent Agreement, issued in 1989, requires the SFWMD to operate the G-92 Structure to provide 50 cfs of flow, when available to the Northwest Fork (**Appendix E**).

The Lainhart Dam, built in the 1930s, and the Masten Dam, have slowed the flow of freshwater through the upper Northwest Fork. Today, the reconstructed Lainhart Dam provides 51-56 percent of the total discharge to the Northwest Fork. In some months, discharge can be as low as 28 percent or as high as 72 percent.

Cypress Creek provides a considerable volume of surface water to the Northwest Fork especially during low flow periods. Located downstream from the Trapper Nelson site in JDSP this tributary enters the river from the west providing on average 26-32 percent of the total flow to the Northwest Fork. This tributary drains a 29,000-acre agricultural area through a network of canals. Flows from this creek are controlled by a structure operated by a local drainage district. The beginning of the Cypress Creek sub-basin is undeveloped wet prairie and acts as a freshwater reservoir for the creek.

The Hobe Grove Ditch drains 10,700 acres of agricultural lands to the east of the Florida Turnpike entering the river at River Mile 9.0. Discharges from this ditch average less than five percent of the freshwater into the Northwest Fork. A water control structure at this ditch is operated by the local groves.

Kitching Creek contributes 11-13 percent of all the flows to the Northwest Fork. This creek is located in an area made up of ponds and marshes that includes properties just north of and within JDSP. Water retention in this area is high due to the fact that is the least developed of all the major tributaries contributing to the Northwest Fork.

Direct rainfall, surface water flow and groundwater seepage are the three sources from which water enters the Loxahatchee River. Rainfall is also the major source of freshwater that fills the surface water bodies and channels in addition to recharging the shallow aquifers. Because of the network of canals and ditches and the lack of storage, most of the rainfall is discharged as stormwater runoff during the rainy season. Therefore, less water is available during the dry season to maintain sufficient flows to the Northwest Fork.

WATER QUALITY

During the last 25 years, the surface waters of the Jupiter Inlet-Loxahatchee River have been extensively sampled and analyzed for water quality. In the 1970s and 1980s, the United States Geological Survey (USGS) provided a water quality monitoring presence from the federal perspective. The FDEP and the SFWMD each sponsored monitoring programs from the state and regional perspective. On the county and local level, the Palm Beach County Health Department, the Palm Beach County Department of Environmental Resources Management and the Loxahatchee River District (LRD) also monitored water quality.

Since 1992, the LRD has assumed responsibility for comprehensive monitoring in the river and monitors 29 stations every other month. In recent years, additional monitoring stations have been added. In the early 1990s, the LRD, in cooperation with a technical advisory committee comprised of representatives of the other monitoring efforts, organized the existing water quality data by collecting and screening all previously collected data. A common database was established and the data presented in a format which could be indexed, composited and compared to Florida State values and standards. The resultant information was further organized by dividing the Loxahatchee River into 29 sample locations in four ecological segments (Marine, Estuarine, Wild and Scenic, and Freshwater Tributaries). Five time-groupings covering 22 specific water quality parameters were developed. This procedure was initiated in 1995 and is updated every six months.

Seven groups of stations have been monitored over the years within the “Wild and Scenic” portion of the Northwest Fork. Additionally, six sampling sites are located in the freshwater tributaries flowing into the Northwest Fork. In general terms, the sampling results show that the water quality of the flows from the freshwater tributaries have remained fair for the period of record between 1970 and1993. The trend is an overall decline in the quality of the inflows from the tributaries over time. However, the water quality trend in the Northwest Fork is graded fair for the first portion of the monitoring period, and the grade improved to good in the mid-1990s.

The major reason for the improvement and apparent inconsistency with the declining quality of the input flows is believed to be the increased flows to the Northwest Fork from the C-18. The C-18 is a Class 1 water body and has rated superior to the other freshwater inputs and has not shown significant degradation over time.

In summary, water quality data have been compiled and analyzed by FDEP to determine current status and trends in this system. Results of this analysis indicate that water quality is generally adequate to meet the designated uses, which include the following:

- C-18, upstream of S-46 - Class 1, Public water supply
- Loxahatchee Slough, C-14 Canal, the Northwest Fork and the North Fork - Class III, Fish and wildlife habitat/natural systems
- Estuarine waters and Aquatic Preserves – Class II, shellfish harvesting

A few exceptions have been noted where these standards are not met periodically at some locations as follows:

- Low levels of dissolved oxygen occur periodically in some parts of the system.
- Total coliform concentrations exceed safe standards in the Northwest Fork near JDSP, in the North Fork near the Girl Scout Camp and at Dubois Park near the Jupiter Inlet.
- Rapid changes in salinity and increased turbidity are associated with high volume releases of freshwater through the S-46 structure on the C-18 canal during and after severe storm events.
- Waters discharged from agricultural lands occasionally contain measurable quantities of pesticides and low concentrations of dissolved oxygen that may cause fish mortality.

Aside from the salinity issues, water quality issues in the Northwest Fork will be addressed through the identification of impaired water bodies and development of Total Maximum Daily Loads (TMDLs) criteria for segments of the river and its tributaries that have significant problems.

WATERSHED MANAGEMENT

WATER SUPPLY

Water withdrawals for public water supply and agricultural irrigation in the basin come directly from either ground water through the surficial or Floridian aquifer, and/or through surface water from lakes. Most irrigation permits with a permitted surface water source also have ground water allowance. Water withdrawals from the surficial aquifer strongly influence the water levels in the adjacent wetlands and affect the ground water discharge to the river and estuary and are therefore limited. Floridian aquifer withdrawals do not influence water flows to the river or estuary but create the need for disposal of the reverse osmosis concentrate, requiring a FDEP permit.

The land uses in the Loxahatchee River Watershed consist of about 20,000 acres of agriculture (11% of the basin), 32,000 acres (18%) urban and industrial, 120,000 acres (67%) water and conservation and 8,000 acres recreational and industrial. Total water use in the basin is estimated at about 100 million gallons per day (mgd), of which, public water supply is 68 percent, agriculture accounts for an estimated 18 percent, and golf courses and industrial uses account for about 14 percent (SFWMD, 2004).

Access to fresh ground water is limited due to shallow aquifers, the saline tides coming from the inlet and the presence of several isolated wetlands to the west. The low permeable fine sand, silt and hardpan beds slow down the vertical flow of water through the mixed layer aquifer. Rainfall provides the major source of freshwater, filling surface water bodies and channels and eventually recharging the shallow aquifer system. Water is generally found between 80 and 150 feet below the surface. Surficial aquifer wells in the watershed draw 150 to 300 gallons per minute depending on the size of the well and the location as it relates to the substrate (SFWMD 2004).

The SFWMD regulates all surface water or ground water withdrawals for consumptive use through permits. Consumptive use permits (CUP) are issued to public water supplies, irrigation, dewatering, industrial etc. Seawater, reclaimed water, and water used for domestic self-supply and fire-fighting excluded from the permitting process. Permits issued have a fixed duration and applicants must reapply for renewal once they expire. To receive a CUP the applicant must demonstrate that the proposed water use is reasonable and beneficial; it will not interfere with other legal users and is in the best interest of the public. The combined annual allocation for all water use permits within the watershed as of May 2002 was 37,672 million gallons per year which is an overall average of about 100 million gallons per day (SFWMD 2004).

During drought conditions, rainfall is unavailable for irrigation and public water supplies and therefore water withdrawals usually increase. Increased withdrawals have the potential to cause significant harm to the water resources in the basin. However, during water shortages, the SFWMD restricts the consumptive use and irrigation withdrawals, based on the concept of equitable distribution between users and the water resources. Under this program there are four levels or phases of water shortage restrictions that are imposed relative to the severity of the drought conditions.

FLOOD PROTECTION

The C-18 Canal, with its many secondary and tertiary networks, is part of the regional primary drainage system of the SFWMD providing flood protection to an area of approximately 210 square miles. The C-18 Canal was constructed through the central portion of the Loxahatchee Slough in 1957 as part of the Central and Southern Florida Flood Control Project (CSFFCP) to improve drainage and provide flood protection for adjacent agriculture, residential, and industrial land as well as J.W. Corbett Wildlife Management area.

The G-92 Structure reconnects the C-18 and the Loxahatchee Slough with the Northwest Fork. As a gated control structure, G-92 can pass 400 cfs in either direction. The structure is operated by remote telemetry from the SFWMD operations control room. Through a joint agreement with the South Indian River Water Control District (SIRWCD), flows are discharged from G-92 to the C-18 District in response to severe storm events. In the dry season, G-92 is designed to convey environmental flows to the Northwest Fork.

A major secondary drainage system, which is adjacent to the Northwest Fork, is operated and maintained by the South Indian River Water Control District (SIRWCD). This system lies west of C-18 and serves a rural-residential area known as Jupiter Farms, and covers an area of approximately 10,315 acres. Seven east-west collector canals drain this area into the C-14 canal, which then directly discharges into the Northwest Fork, just south of the Indiantown Road Bridge. A North-South canal, C-14, parallels the C-18, re-diverting water from the C-18 back to the Northwest Fork through G-92. The C-14 ends where the natural meandering pattern of the river begins in the Northwest Fork.

Water control structure S-46, the primary flood control facility for the Loxahatchee River Watershed, is a reinforced concrete, gated spillway located on the C-18 with discharge controlled by three stem-operated, vertical lift gates. Structure S-46 also supports water level upstream and downstream by remote digital recorders, a gate position recorder and a rain gauge remote digital recorder. Gates are automatically controlled so that the operating system opens or closes the gates in accordance with the standard operational criteria. Structure S-46, located on C-18 about 0.5 mile east of the Florida Turnpike/Interstate 95 (I-95) maintains optimum upstream water control stages in the C-18. The S-46 structure is designed to pass 50 percent of the Standard Project Flood without exceeding the upstream flood design stage; it restricts downstream flood stages and channel velocities to non-damaging levels. (SFWMD 2004)

The managed water levels in the river and canal systems of the Loxahatchee provide for drainage of land and storage of water during the wet season. It also provides adequate conveyance capacity to protect lives and property in the surrounding upland residential areas from flood damage during severe storm events. The amount of water that is able to be stored in the basin is limited, due to the lack of storage. Because there is limited storage area available, water is discharged to tide in order to provide adequate flood protection for the area.

NAVIGATION AND RECREATION

The Loxahatchee River's natural features and its proximity to the urban areas of Southeast Florida make it exceptionally well suited to provide outdoor recreation. Historically, canoeing has been the main recreational use of the Northwest Fork and its surrounding area, but other activities include kayaking, fishing, nature study, wildlife observation and motor boating. Motor boating in the Northwest Fork is effectively restricted to areas downstream from Trapper Nelson Interpretive Site because of the naturally narrow channel, numerous natural obstructions and natural shallow depth of the upper reaches.

The reaches of the Northwest Fork included in the "Wild and Scenic" designation have relatively limited public access points. Existing access and major facilities that support public use are clustered at each end of the "Wild and Scenic" portion of the Northwest Fork. Most existing river-related recreational uses and major facilities occur within JDSP, but in the future other facilities will be provided and managed by Palm Beach County Department of Recreation at Riverbend Park. Riverbend Park is located south of Indiantown Road and west of the C-18 Canal.

It comprises more than 600 acres and encompasses a half mile long “recreational” segment of the Northwest Fork.

An important function of the river management program for the Northwest Fork is to determine and monitor the quantity and mixture of recreation and other public use, which can utilize the river without adverse impacts on its resource values. The recreation “carrying capacity” of rivers has received the attention of river managers for more than a decade, but there is little consensus as the most appropriate means for estimating carrying capacity. This is because carrying capacity is dynamic concept and a number of factors exist, including management objective, the physical and biological nature of the resource, and the preferences and tolerances of users, which must be considered together in determining a river’s capacity (FEDP and SFWMD 2000).

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AN OVERVIEW

The upstream floodplains, freshwater and tidal, of the Northwest Fork and the Loxahatchee River Estuary are unique regional resources in several ways. Much of the Loxahatchee River watershed's natural areas remain intact. Within the Jonathan Dickinson State Park (JDSP) the rare biological community of coastal sand pine scrub is found. Other terrestrial habitats found within the watershed include pinelands, xeric oak scrub, hardwood hammocks, freshwater marshes, wet prairies, cypress swamps, mangrove swamps, seagrass beds, tidal flats, oyster beds and coastal dunes (Treasure Coast Regional Planning Council 1999). There are also distinct aquatic environments within the Loxahatchee River system: the freshwater zone, the oligohaline (low salinity) zone, the mesohaline zone, and the polyhaline zone. These terrestrial and aquatic habitats support diverse biological communities including many protected species such as the manatee, an aquatic mammal which is restricted to Florida during the winter, and the four-petal pawpaw, a tree which is found only in Martin and Palm Beach counties. The Northwest Fork of the Loxahatchee River is home to one of the last vestiges of native cypress floodplain swamp within southeast Florida.

THE NORTHWEST FORK

Some of the first changes to this natural system occurred in the 1930s when private individuals constructed the Lainhart and Masten dams on the Northwest Fork to maintain water levels in the Northwest Fork. Re-constructed in the 1980s these dams helped to maintain higher surface water levels behind the dams, especially in the dry season, thereby reducing over drainage of the area. During the 1950s, the C-18 Canal was built through the Loxahatchee Slough to provide flood protection and to redirect water to the Southwest Fork. This project greatly reduced freshwater flows to the Northwest Fork and in 1974, the North-South Canal, C-14, was built to re-direct water from the C-18 Canal back into the Northwest Fork. The C-14 Canal ends where the natural meandering of river begins in the Northwest Fork. The G-92 Structure was also constructed during this time allowing a flow of 50-100 cfs through the Northwest Fork at the intersection of C-18 and the Northwest Fork. Today G-92, a gated control structure now operated by remote telemetry, allows up to 400 cfs of water to flow into the Northwest Fork. In addition, a 1989 agreement between the South Indian River Water Control District, the SFWMD, and the Loxahatchee River Environmental Control District (LRD) allowed for flows through G-92 into the Northwest Fork when feasible (**Appendix G**).

Within the natural river channel, the Northwest Fork averages 3 to 6 feet deep (Chiu 1975) with a maximum depth ranging up to 16 feet near Cypress Creek. Maximum depths further upstream (beyond RM 10.3) are generally less than 10 feet. Most of the watershed remains in a natural, undeveloped state, protected in parks or preserves or in low-intensity agricultural use leaving the water quality of the runoff good in most areas.

The estuarine portion of the Northwest Fork begins at the embayment (RM 2.5) and extends upstream approximately 2 miles to RM 4.5. From there, the estuary narrows significantly and becomes the river channel. The average width of this estuary segment is about one-half mile with a depth of 4.2 to 12.5 feet and covers 320 acres.

The Northwest Fork originally drained most of the Loxahatchee River basin and continues to provide about 65 to 67 percent of the total freshwater flow to the estuary during the wet season and 89 to 94 percent during the dry season. The brackish waters in this area are dependent upon flows and tides. Bottom salinities in the Northwest Fork remain above 25 ppt (parts per thousand) and range from 20 ppt to 35 ppt during typical wet season conditions. During extreme storm-related discharge events, salinities can drop below 10 ppt (Russell and McPherson 1984). This brackish water system supports diverse communities of estuarine fish, benthic fauna and oyster populations in its upper portions and marine seagrass communities as it nears the embayment.

THE ESTUARY

Saline waters from the Atlantic Ocean flow through the Jupiter Inlet and merge with the freshwaters flowing from the North, Northwest and Southwest Forks of the Loxahatchee River to form the Loxahatchee Estuary or Embayment. This shallow embayment has an average depth of 3.5 feet , a maximum depth of 15 feet and covers an area of 380 acres (Russell and McPherson 1984; FDEP 1998; Antonini et al. 1998).

Development along the east coast of Florida has changed the hydrology of the Loxahatchee River Estuary. The Jupiter Inlet once opened and closed because of natural events. During storm events the inlet was kept open due to flows from the Loxahatchee River, Lake Worth Creek and the southern part of the Indian River Lagoon. However at the turn of the century, the construction of the Intracoastal Waterway and Lake Worth Inlet and modifications to the St. Lucie Inlet diverted water flows and caused the inlet to remain closed most of the time. Since 1947, the Jupiter Inlet has been kept permanently open by the Jupiter Inlet District (JID).

THE FLOODPLAIN ECOSYSTEM

In this section, the characteristics of the floodplain forest reaches and community types found on the Northwest Fork of the Loxahatchee River will be examined. River floodplains are an important part of any watershed system. They provide storage and filtration of surface water, diverse habitats for plants and animals, corridors for the movement of animals and dissemination of plants, and provide a supply of nutrients to estuarine environments (Darst et al. 2003). In Mitsch and Gosselink (1993) these riparian zones are described as “the interface between terrestrial and aquatic ecosystems.” Gregory et al. (1991) described riparian zones as ecotones that encompass distinct gradients of environmental factors, ecological processes and plant communities and are composed of mosaics of landforms, communities and environments within larger landscapes.

The floodplains of the Northwest Fork of the Loxahatchee River consist of tropical and temperate zone riparian forest. As a riparian forested wetland system, these vegetative communities vary from dry to occasionally flooded as the river and its tributaries react to local rainfall events. Hydric and mesic hammocks commonly signify a higher elevation within the floodplain topography. Riparian forests are generally referred to in the Southeastern United States as bottomland hardwood forests. They contain diverse vegetation that varies along gradients of flooding frequency. These forests are generally considered to be more productive than the adjacent upland forests because they receive a periodic inflow of nutrients, especially when flooding is seasonal rather than continuous (Mitsch and Gosselink 1993). Swamps are defined as woody wetlands that have standing water for most if not all of the growing season. Swamps on the floodplains of the Loxahatchee River consist primarily of bald cypress (*Taxodium distichum*), red and white mangroves (*Rhizophora mangle* and *Laguncularia racemosa*), pond apple (*Annona glabra*) and pop ash (*Fraxinus caroliniana*). The Loxahatchee River contains some of the last pristine subtropical cypress swamps in Southeast Florida.

HISTORICAL FLOODPLAIN STUDIES

During April 1967, Taylor Alexander studied vegetation quadrats along a transect on the Northwest Fork of the Loxahatchee River near RM 7.5 (personal communication). His transect contained temperate and subtropical species, salt tolerant and non-salt tolerant species, and three classes of cypress trees: dead, stressed but living, and healthy. His transect was reexamined in the FDEP/SFWMD 2003 vegetative study and one living cypress was found.

Alexander and Crook (1975) utilized aerial photographs and groundtruthing to examine plant communities along the Northwest Fork of the Loxahatchee River and Kitching Creek (**Figure 3-1**). Upon identifying the signature of the most abundant community types, they were able to use photo interpretation to identify the major vegetative communities from a 1940 aerial photograph. Areas of dead and living cypress canopy within a mangrove understory were then field verified in 1970. They concluded that since 1940, areas of wet prairie and swamp hardwoods had been converted to pinelands and mangrove communities because of the lowered groundwater table and the saltwater encroachment between RM 6.0 and RM 8.0. They were able to identify areas of past logging in the aerial photographs, which could explain the loss of mature trees within portions of the watershed. Also, they mentioned the impact of fire, hurricanes and heavy frost on the major plant communities. At RM 6.5, they collected freshwater peat at a depth of 24 inches below the surface. Based on this information, they further concluded that there was no evidence that cypress forest had extended much further downstream than about RM 6. Finally, Alexander and Crook (1975) predicted that the mangrove invasion would accelerate, if anthropogenic activities in the upper floodplain of the river further reduced the freshwater head.

Figure 3-1. Photograph of the Northwest Fork of the Loxahatchee River taken in 1971 by T. Alexander.

Between 1979 and 1982, Duever (personal communication) documented the extent of environmental stress in the bald cypress community along the Northwest Fork of the Loxahatchee River. The study examined core samples collected from cypress trees at 21 sites (69 trees in total) located along the river to identify changes in tree rings over time. The results of the study indicated that although all of the trees sampled had experienced stress at periodic intervals during their life histories, the proportion of stressed trees downstream of RM 9.0 increased from 30 percent in 1940 to 80 percent in 1982 (**Figure 3-2**). The proportion of stressed trees upstream from RM 9.0 decreased from 11 percent to 3 percent during the same 40-year period (**Figure 3-3**). The study also found a high correlation between the incidence of growth stress and high salinity in surface water and soils.

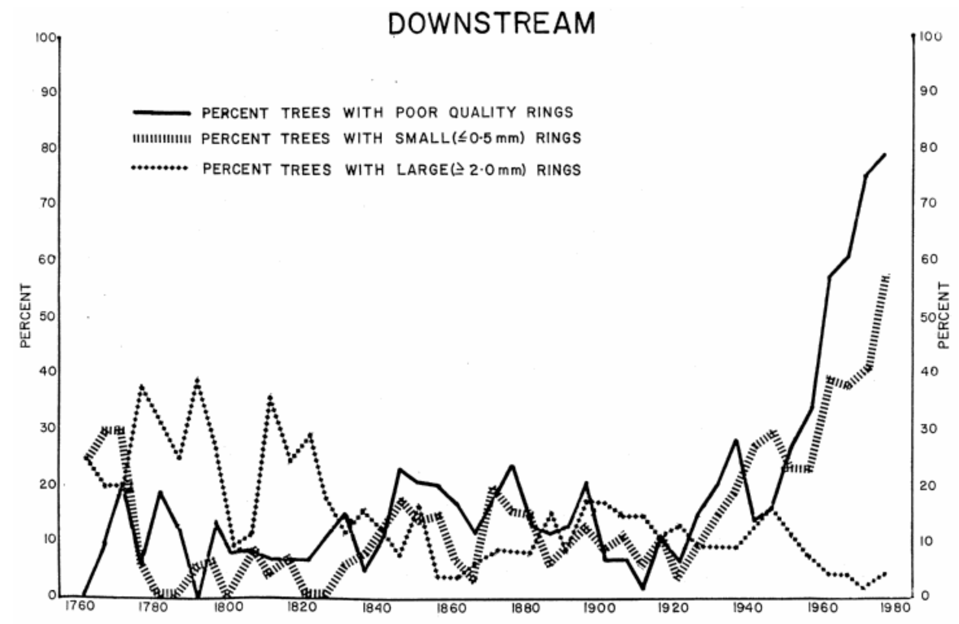

Figure 3-2. Changes in Cypress Tree Ring Size and Quality Through Time Downstream of RM 9.0, Northwest Fork of the Loxahatchee River (from Duever, unpublished USGS data).

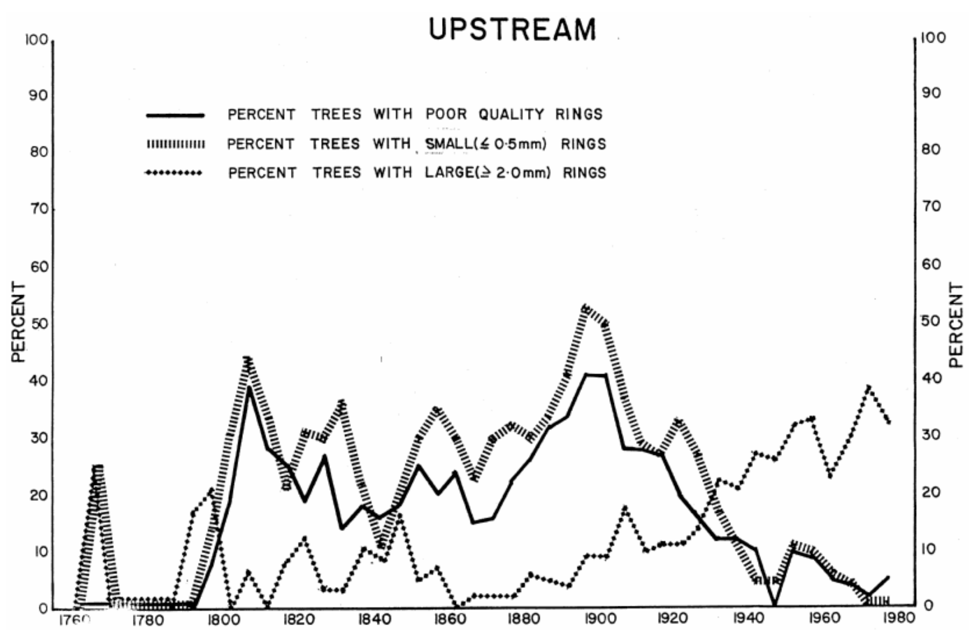

Figure 3-3. Changes in Cypress Tree Ring Size and Quality Through Time Upstream of RM 9.0, Northwest Fork of the Loxahatchee River (from Duever, unpublished USGS data)

McPherson (1981) studied the transitional area between the cypress forest community and the mangrove community on the Northwest Fork. In May of 1981, the surface salinities around an area of dead and stressed cypress were 20 to 30 ppt. In another area of intermediately stressed cypress, surface salinities ranged from 15 to 20 ppt. In areas with shallow groundwater, salinities decreased as depth below the land surface increased and distance from the river increased, especially in areas where freshwater seepage was observed from nearby higher pinelands. McPherson concluded that there was no evidence that cypress forest ever extended much further downstream from his Site 7E (approximately RM 5.5) on the Northwest Fork.

Dewey Worth established six, 10m wide vegetation transects along the Northwest Fork of the Loxahatchee River as a part of South Florida Water Management District's Loxahatchee River Restoration Plan (1983-1984). The transects were surveyed and ground and surface water elevations were recorded. In addition, several shallow groundwater monitoring wells were established. SFWMD scientists have obtained the datasets to examine for trends.

Between October 1993 and January 1994, Ward and Roberts (1996) re-examined Worth's six vegetative transects between Indiantown Road (S.R. 706) and the mouth of Kitching Creek. Each 10m wide belt transect was partitioned into $10m^2$ plots. A total of 79 plots were surveyed during the study. Generally the density (stems/hectare) of bald cypress (*Taxodium distichum*) increased upstream from Transect #6 (RM 8.4) near Kitching Creek to Transect #1 (RM 14.5) just north of S.R. 706. A noticeable decrease in cypress density occurred at Transect #3 (RM 12.1), which was heavily populated with pop ash (*Fraxinus caroliniana*), red maple (*Acer rubrum*) and cabbage palms (*Sabal palmetto*). These six transects (**Figure 3-4**) were re-examined in the 2003 vegetative study and four new transects were added. Comparisons of the 1993-1994 and 2003 vegetation studies are being prepared for a report summarizing the 2003 vegetation survey.

Figure 3-4. Location of the 10 Vegetation Transects of the Northwest Fork of the Loxahatchee River.

Note: Transects #1 – #6 are D. Worth transects (1983-1984); Transects #7 - #10 are Ward and Robert (1996) transects.

In an examination of aerial photography from 1940 to 1995, major vegetative communities were identified along the floodplains of the Northwest Fork of the Loxahatchee River (SFWMD 2002). The results of the study indicated that the floodplain vegetation coverage had decreased due to shoreline bulkhead construction, filling for development, Jupiter Inlet stabilization in 1947, and changes in vegetation types (i.e. changes from wetlands to transitional and upland species, from marsh to mangrove, and from wet prairie to pine forest). The 1940 aerial photographs of the watershed indicate an abundance of swamps, wet prairies, inland ponds, and sloughs. Freshwater swamp hardwood and cypress communities were dominant from RM 4.5 to RM 8.9, comprising about 73 percent of the vegetative coverage, while mangroves represented 22 percent (**Figure 3-5**). Mangroves were dominant from RM 4.5 to RM 6.0 and were present upstream to RM 7.8. By 1985, freshwater communities represented 61 percent of the coverage, while mangroves represented 25 percent of the coverage. Mangroves were dominant between RM 5.5 and RM 8.7 and extended up to RM 10.5. There was a loss of approximately 80 acres of mangroves due to development between RM 4.5 and RM 5.5. **Figure 3-6** shows the 1995 floodplain vegetation coverage. There were no major changes between cypress and mangrove floodplain coverages between 1985 and 1995.

Semi-quantitative and quantitative vegetation surveys (species composition and abundance) were conducted along the Northwest Fork of the Loxahatchee River as a part of the Minimum Flows and Levels Project (Zahina 2004). Twenty-three semi-quantitative sites were sampled in November 2000 and December 2001. Eight sites were re-investigated from the series of semi-quantitative survey sites to produce a quantitative database in 2002. The vegetation studies indicate a decline in species richness, reduction in tree height, reduction in canopy diameter and in stem diameter that was related to salinity. The report addressed distribution of plant species and communicates along the salinity gradient, and the relationship between salinity exposure and freshwater floodplain decline.

In 2003 vegetation and groundwater monitoring studies were established for plant community composition and structure and groundwater in order to document baseline and future plant community health along the floodplains of the North and Northwest Forks of the Loxahatchee River and Cypress and Kitching Creeks. The project examined the six historical vegetation transects and established four new transects in additional areas of concern (**Figure 3-4**). These locations are representative of riverine (predominantly non-impacted freshwater) and upper tidal (saltwater intruded with fresh and brackish water) communities. Seven transects are located at designated locations along the middle and upper segments of the Northwest Fork of the Loxahatchee River. Additional transects were established in the lower segment of Kitching and Cypress Creeks (tributaries of the Northwest Fork), and in the upper North Fork of the Loxahatchee River. Data from the historical transects of Alexander (1967, unpublished), Worth (1984, unpublished SFWMD), and Ward and Roberts (1993-1994, unpublished) will be compared with the 2003 baseline data to determine changes in the composition and structure of these forest communities over time.

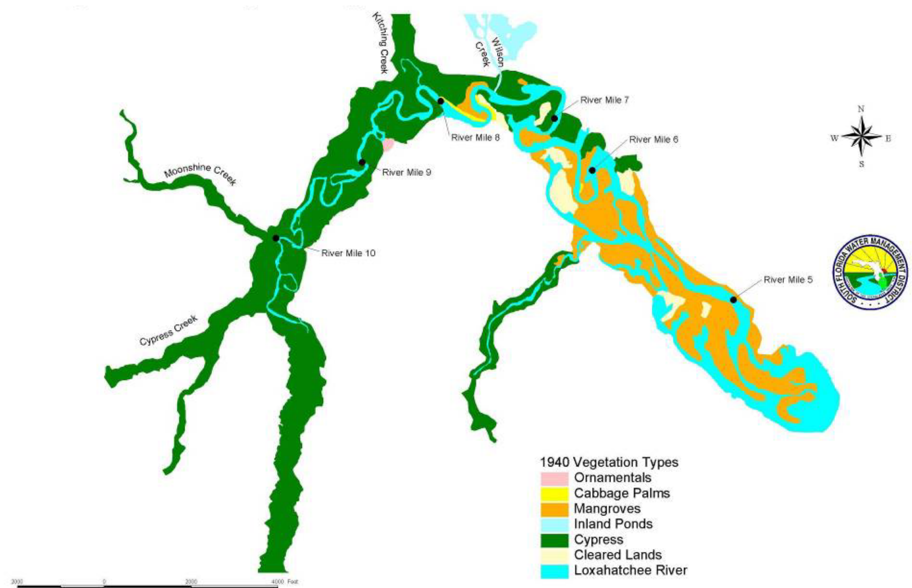

Figure 3-5. 1940 Aerial Interpretation of Floodplain Vegetative Communities Along the Northwest Fork of the Loxahatchee River.

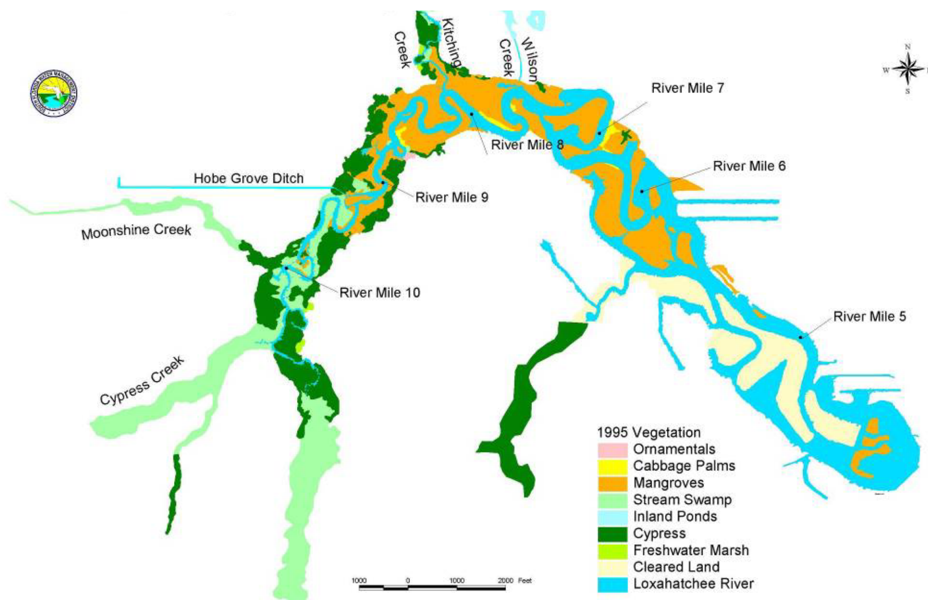

Figure 3-6. 1995 Aerial Interpretation of Floodplain Vegetative Communities Along the Northwest Fork of the Loxahatchee River.

For the analysis of canopy data from the 2003 Vegetation study, plant communities of the floodplains of the Northwest Fork of the Loxahatchee River were divided into three distinct groups or reaches (**Table 3-1** and **Figures 3-7a** and **3-7b**) **riverine (R)**, **upper tidal (UT)** and **lower tidal (LT)**. These groups were distinguished based on hydrological conditions, vegetation, and soils (modified from USGS 2002a). The boundaries were based on distribution of the different canopy tree species using the 1995 aerial photography and the corresponding GIS coverage. The Northwest Fork of the Loxahatchee River contains approximately 320 hectares of riverine, 24 hectares of upper tidal and 45 hectares of lower tidal floodplain forests.

Table 3-1. Forest Community Types by Reach for the Northwest Fork of the Loxahatchee River and its Major Tributaries.

Forest Type	Riverine (R)	Upper Tidal (UT)	Lower Tidal (LT)
Swamp	Rsw1 Rsw2 (FPsw1 [a])	UTsw1 UTsw2 (FPsw1[a]) UTsw3 (LRsw3[b])	LTsw1 (RMsw1[c]) LTsw2
Low Bottomland Hardwood High Bottomland Hardwood	Rblh1 Rmix Rblh2 Rblh3	UTmix	LTmix
Hammock	H (Mesic and Hydric)	H (Hydric only)	H (Hydric only)
Upland	U	U	U

[a] Another name for *Fraxinus caroliniana* swamp.

[b] Another name for *Laguncularia racemosa* swamp.

[c] Another name for *Rhizophora mangle* swamp.

Riverine reach information is generally presented in this report with a green background color. Upper tidal reach information is generally presented in this report with a yellow background color. The lower tidal reach information in this report is generally presented with a beige color background.

The riverine reach is that part of the floodplain forest having primarily freshwater canopy forest that is generally unaffected by salinity. On the Northwest Fork of the Loxahatchee River, this area ranges from just north of the G-92 Structure (**Figure 3-7b**) downstream to RM 9.5 (**Figure 3-7a**). Vegetative communities in this reach are dominated by bald cypress (*Taxodium distichum*) with pop ash (*Fraxinus caroliniana*), red maple (*Acer rubrum*), pond apple (*Annona glabra*), water hickory (*Carya aquatica*) and other trees present with less frequency.

The upper tidal reach is that part of the floodplain forest having a mixed freshwater/brackish canopy forest that has experienced some saltwater intrusion due to tidal influences and lack of freshwater flow in the dry season. On the Northwest Fork of the Loxahatchee River this area occurs between RM 9.5 and RM 8.13 (the mouth of Kitching Creek), as illustrated in Figure 3-7a. Upper tidal reach communities are dominated by pond apple, red and white mangrove (*Rhizophora mangle* and *Laguncularia racemosa)* and cabbage palm (*Sabel palmetto)* with some communities of bald cypress present in the inner floodplain areas away from the riverbed.

The lower tidal reach is that part of the Northwest Fork having primarily salt tolerant species and is highly influenced by tides and salinity in the water and soils (**Figure 3-7a**). This area extends from approximately RM 8.13 to RM 5.5 although several smaller areas can be found around RM 4.5 and in the embayment area. The lower tidal reach is dominated by red and white mangrove.

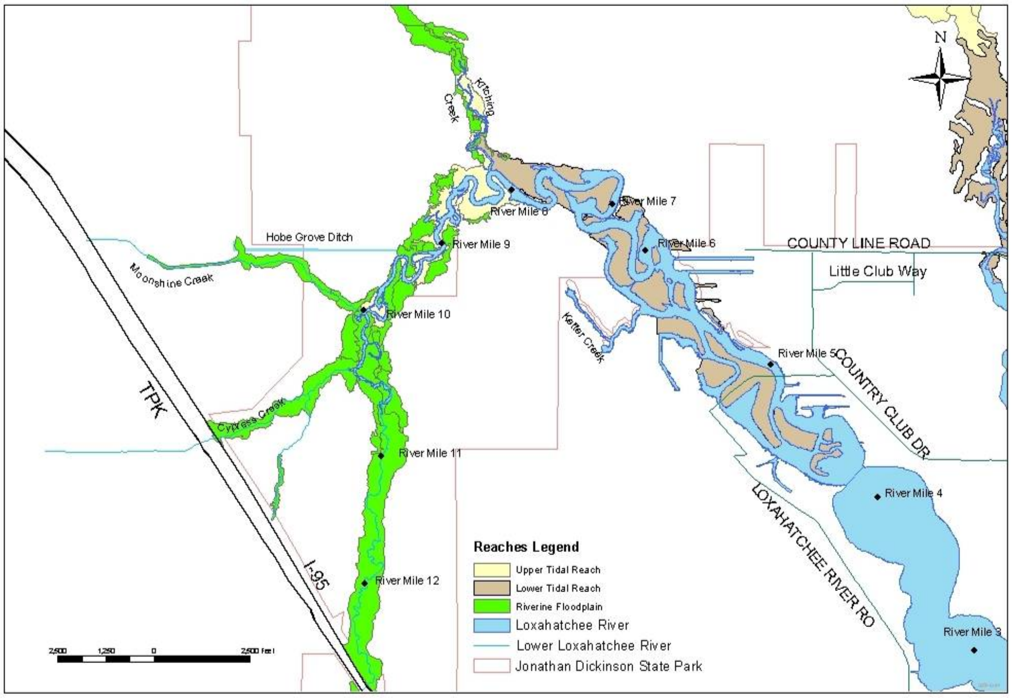

Figure 3-7a. Reaches of the Northwest Fork of the Loxahatchee River Between RM 4.5 and I-95 (RM 12.76).

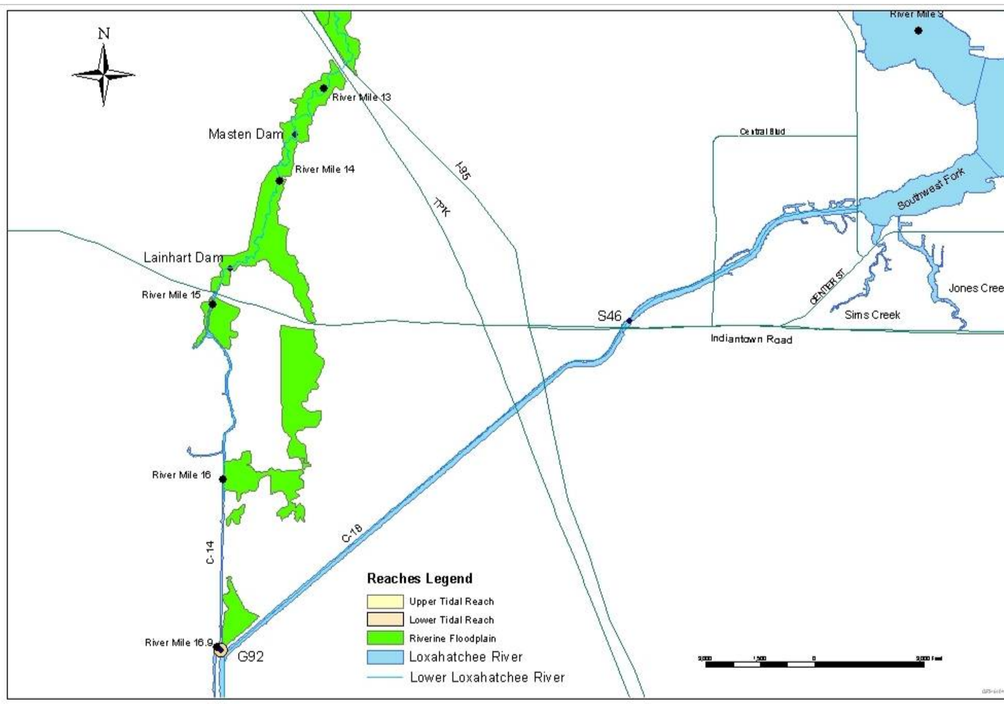

Figure 3-7b. Upper Riverine Reach of the Northwest Fork of the Loxahatchee River Between I-95 (RM 12.76) and the G-92 Structure.

DESCRIPTION OF FLOODPLAIN FOREST COMMUNITIES

The identification of floodplain forest community type was based on the canopy tree species that generally grow together in recognizable communities (modified from Darst et al. 2003). Tree canopy data from both the 1995 Ward and Roberts study (76 $10m^2$ plots) and the 2003 transect study (130 $10m^2$ plots) were collected; the relative basal area (RBA) of each tree species within a plot was determined using diameter at breast height (dbh) measurements. RBA is calculated by dividing the total basal area of a species (in m^2) by the total basal area of all species within a $10m^2$ plot. Multi-trunk trees were considered separate trees for this analysis. The most common multi-trunk trees observed were pond apple (*Annona glabra*), red mangrove (*Rhizophora mangle*) and bald cypress (*Taxodium distichum*).

Forest Community Types

Guidelines were developed to identify the 15 forest community types by reach (**Table 3-2**). For each area, the major vegetative community category was identified as swamp (S), bottomland hardwood (low and high Blh), hydric or mesic hammock (H), or uplands (U). Then the reach and type of the forest community was determined based on species composition. Using these guidelines, it was possible to consistently distinguish among forest community types (i.e., distinguish a riverine swamp community from an upper tidal swamp community).

Split plots and mixed plots also occurred. A split plot had two major forest types split 50-50 based on relative basal area (RBA) on either side of the plot such as Hammock/Rsw1. A mixed plot has several forest types mixed together within the plot. These plots were classified as Rmix, UTmix, or LTmix. A total of 28 canopy species were identified during the 2003 belt transect survey and were categorized by their most common occurrence in the floodplains. Forest types clearly differ as a result of changes in hydrology, topography, vegetation, soils, and proximity to the coast (Darst et al. 2003). Other factors that influence forest type include logging and fire history, presence or absence of exotic species, and the availability of nutrients and light.

DuBois wrote in her book “The History of the Loxahatchee River” (1981) that logging leases to two townships on the Loxahatchee were purchased by the Hunt brothers from Green Cove Springs in 1891. Other logging operations were conducted, cutting pine from the uplands and cypress from the river’s edge. After logging a portion of their property, local pioneers, John and Bessie DuBois purposely saved 27 large cypress trees on Kitching Creek. The last recorded logging operations on the Loxahatchee River were in 1941. The cypress swamp community on the Upper Northwest Fork near Indiantown Road (S.R. 706) remains largely intact. Many of the cypress trees along this reach of the river range from 300 to 500 years in age. Evidence of past logging activities on the Transects #3, #6, and #7 was verified by the presence of tree stumps without the fallen trees.

Oak/pine upland forests are present in both the riverine and tidal reaches of the floodplain and are inundated only for short periods of time during the highest floods. Most of the species found in this forest community type can only survive brief periods of inundation. On the Northwest Fork of the Loxahatchee River, these upland systems are dominated by slash pine (*Pinus elliottii*), myrtle oak (*Quercus myrtifolia*) and saw palmetto (*Serenoa repens*). Brazilian pepper (*Schinus terebinthifolius*) may occur as an exotic pest species in many of the forest community types if there is sufficient elevation for its growth.

Table 3-2. Guidelines for Determining Reach and Forest Type (2003 Canopy Study) in the Floodplains of the Loxahatchee River and its Major Tributaries (modified from Light et al. 2003).

Category		Species	Rules for Determination of Reach
Swamp	Riverine	*Fraxinus caroliniana* *Taxodium distichum*	1) IF *Taxodium distichum* + *Fraxinus caroliniana* + *Acer rubrum* + *Carya aquatica* > 80% THEN reach is riverine. 2) IF *Taxodium distichum* + *Acer rubrum* + *Carya aquatica* < 20% and *Annona glabra* + *Fraxinus caroliniana* > 60% OR 3) IF *Rhizophora mangle* + *Laguncularia racemosa* + *Fraxinus caroliniana* > 60%, THEN reach is upper tidal. 4) IF *Rhizophora mangle* > 80% OR 5) IF *Rhizophora mangle* + *Laguncularia racemosa* > 75% and *Annona glabra* <10%, THEN reach is lower tidal.
	Tidal	*Annona glabra* *Laguncularia racemosa* *Rhizophora mangle*	
Bottomland Hardwood (blh)	Low	*Acer rubrum* *Cephalanthus occidentalis* *Persea palustris* *Salix caroliniana* *Syzygium cumini*	**Rules for Determination of Forest Type** 1) IF Upland ≥ 75%, THEN forest type is upland. 2) IF Upland < 50% and hammock > 50%, THEN forest type is hammock. **Riverine reach forest types:** 1) IF riverine swamp > 50% THEN 2) IF *Taxodium distichum* ≥ 80%, OR
	High	*Carya aquatica* *Chrysobalanus icaco* *Citrus* spp. *Ilex cassine* *Psidium cattleianum* *Quercus laurifolia* *Roystonea regia*	3) IF *Taxodium distichum* + *Fraxinus caroliniana* ≥ 80% and *Taxodium distichum* > 50% THEN forest type is Rsw1. 4) IF *Fraxinus caroliniana* ≥ 80%, OR 5) IF *Taxodium distichum* + *Fraxinus caroliniana* > 80% and *Fraxinus caroliniana* > 50%, THEN forest type is Rsw2. 6) IF *Taxodium distichum* < 50% and hammock > 40% but < 60 % THEN forest type is Rmix.
Hammock		*Ficus microcarpa*[a] *Ficus aurea*[a] *Myrica cerifera* *Persea borbonia* *Quercus virginiana*[c] *Sabal palmetto*[d]	7) IF riverine swamp < 50% THEN 8) IF low blh > 80%, OR 9) IF *Acer rubrum* ≥ 80%, THEN forest type is Rblh1. 10) IF high blh + low blh > 80% and high blh > 50%, THEN forest type is Rblh2. 11) IF high blh + up or hammock ≥ 70%, THEN forest type is Rblh3. 12) IF hammock ≥ 80%, OR 13) IF hammock + high blh is > 80% and hammock > 50%, Then forest type is hammock. **Upper tidal reach forest types:** 1) IF mixed swamp[b] ≥ 70% and *Laguncularia racemosa* <30%, THEN forest type is UTsw1. 2) IF mixed swamp[b] < 70% and *Annona glabra* > 30%, THEN forest type is UTsw2. 3) IF *Lagunularia racemosa* > 50% THEN forest type is UTsw3.
Upland		*Pinus elliottii* *Quercus myrtifolia* *Schinus terebinthifolius* *Serenoa repens*	4) IF mixed swamp[b] < 50% and hammock + upland > 60% OR 5) IF hammock + blh < 75%, THEN forest type is UTmix. 6) IF hammock > 75%, THEN forest type is hammock. **Lower tidal reach forest types:** 1) IF LT swamp > 50% OR 2) IF *Rhizophora mangle* is > 80%, THEN forest type LTsw1. 3) IF *Laguncularia racemosa* + *Annona glabra* is > 70%, THEN forest type is LTsw2. 4) IF LT swamp < 50% THEN, 5) IF *Sabal palmetto* ≥ 50% and *Laguncularia racemosa* + *Annona glabra* > 40%, THEN forest type is LTmix. 6) IF *Sabal palmetto* + *Chrysobalnus icaco* ≥ 75%, THEN forest type is hammock.

[a] Present as epiphytes at Transects #7 and #9.
[b] Both riverine and tidal swamp species present.
[c] Dominant canopy species in Mesic Hammock.
[d] Dominant canopy species in Hydric Hammock.
Species in Red Font-are Exotics.

Hammocks are also found in both the riverine and tidal reaches of the Loxahatchee River. Hammocks support a vast diversity of tropical and subtropical plants including hardwood trees, palms, orchids and other epiphytes (Mitch and Gosselink, 1993). Hydric hammock communities are dominated by cabbage palms (*Sabal palmetto*) whereas mesic hammocks are dominated by live oaks (*Quercus virginiana*). Mesic hammocks are found at higher elevations than hydric hammocks. No mesic hammocks were found in the tidal reaches of the Loxahatchee River. Other fairly common species in hammock areas are myrsine (*Rapenea punctata*), mulberry (*Morus rubra*), red bay (*Persea borbonia*), and ficus (*Ficus aurea*). Hammocks are generally found between the uplands, bottomland hardwood and swamp areas, although with changes in elevation within the floodplain they may appear as isolated islands or may border the riverbed where elevations are higher. Hammocks are briefly inundated by storm surges but characteristically have a high water table due to their proximity to deeper wetland areas. Hydric hammocks are flooded continuously for several weeks or longer every 1 to 3 years depending on reach. Mesic hammocks are rarely flooded because of their high elevations. Soils are generally sandy in both types of hammock.

In the riverine reach, high bottomland hardwoods are found on higher ridges while low bottomland hardwoods are found on swamp margins. Periods of inundation generally occur for 1 to 2 months every few years for high bottom land hardwood (Rblh2 and Rblh3) and about 2 months of every year for low bottomland hardwood (Rblh1). Characteristic Rblh1 species include red maple (*Acer rubrum*), buttonbush (*Cephalanthus occidentalis*), swamp bay (*Persea palustris*) and Carolina willow (*Salix caroliniana*) while characteristic Rblh3 species are water hickory (*Carya aquatica*), cocoplum (*Chrysobalanus icaco*), dahoon holly (*Ilex cassine*) and laurel oak (*Quercus laurifolia*). The forest type Rblh1 is characterized by a dominance of red maple and is found at lower elevations than either Rblh2 or Rblh3. The forest type Rblh2 has approximately equal amounts of low and high bottomland species whereas the Rblh3 forest has combinations of high bottomland mixed with hammock species or even some upland representatives. The Riverine Mixed (Rmix) forest type is characterized by even more disparate species: bald cypress and hammock species are almost equally mixed. The exotic plant species, java plum (*Syzgium cumini*) and strawberry guava (*Psidium cattleianum*) are found in disturbed areas of the riverine and tidal bottomland hardwoods. The occurrence of a few royal palms (*Roystonea regia*) is attributed to their spread from the adjacent Ornamental Garden property. Java plum and strawberry guava may have been introduced by Trapper Nelson.

Riverine swamps are characterized with the lowest elevations and wettest areas with either inundation or saturation most of the year. Soils are generally sandy with some loam and clay. On the Northwest Fork of the Loxahatchee River, older riverine swamps are dominated primarily by bald cypress (*Taxodium distichum*) communities (Rsw1; **Figure 3-8**), while younger subcanopy swamp communities and impacted areas (i.e. logged) are dominated by pop ash (*Fraxinus caroliniana*, Rsw2). Occasional bald cypress/cabbage palm (swamp/hammock) and bald cypress/red maple/cabbage palm (swamp/low bottomland hardwood/hammock) communities are present and are categorized as Riverine Mixed (Rmix). Pond apples are found in the riverine swamps but are generally only associated with the riverbanks.

Figure 3-8. An Example of Forest Type Rsw1 (Bald Cypress Swamp).

As with riverine swamps, upper tidal swamps are present at elevations below median monthly high stage. Unlike riverine swamps, upper tidal surface soils are generally permanently saturated mucks. On the Northwest Fork of the Loxahatchee River, upper tidal swamps are a mixture of brackish and freshwater vegetative communities primarily consisting of pond apple, red and white mangrove (*Laguncularia racemosa*) with smaller amounts of bald cypress, pop ash, red maple and Carolina willow (**Table 3-2**).Areas of riverine swamp Rsw1 (i.e. mostly older bald cypress) are present and have probably survived at the back of the tidal floodplains as a result of surface and groundwater runoff from the adjacent uplands. UTsw1 is defined as a community of 70 percent mixed swamp with less than 30 percent white mangrove while UTsw2 is defined as less than 70 percent mixed swamp but with greater than 30 percent pond apple. White mangroves are more dominant in the UTsw3 forest type. White mangroves are generally found at higher elevations than red mangrove, bald cypress, and pop ash; therefore, they should represent less relative basal area in the deeper mixed swamp communities. When mixed swamp communities are less than 50 percent and hammock, uplands and/or bottomland hardwood species are greater than 60 percent, then the forest type is identified as upper tidal mixed (UTmix; **Figure 3-9**). However, if hammock represents greater than 75 percent then the forest type is identified as hammock. No bottomland hardwood plots are found in the upper or lower tidal reaches.

Figure 3-9. An Example of Forest Type UTmix (Pond Apple, Bald Cypress, Red Maple, Wax Myrtle and Cabbage Palm in a Selectively Logged Area).

Lower tidal forest types are primarily mangrove forest (i.e. swamps) with some areas of hammock which represent areas with very little change in topography within the floodplains. Soils are generally mucky with some areas of sand. LTsw1 is representative of a swamp dominated by red mangrove (**Figure 3-10**). The LTsw2 is representative of a white mangrove swamp with infrequent pond apple and red mangrove (**Figure 3-11**). Other plots contain mixtures of white mangrove, pond apple, and cabbage palm. If cabbage palm is at least 50 percent and white mangrove and pond apple are greater than 30 percent than the forest type is identified as lower tidal mixed (LTmix). If cabbage palm and cocoplum (*Chrysobalnus icaco*) are greater than 75 percent then the forest type is identified as hammock. Cabbage palm is found intermixed and in clumps with swamp species; however those palms that were found at these low elevations and exposed to salt water did not appear to be as healthy as those found at obviously higher elevations. Other palms were found growing on small mounds or hummocks. Today, cabbage palms are quite common along the shoreline of the tidal Northwest Fork of the Loxahatchee River. The river channel has widened between 1940 and 1995 between the JDSP boundary at RM 5.92 and Trapper Nelson's Interpretative Site at RM 10.50 (SFWMD 2002). This widening suggests that erosion has occurred within these cabbage palm communities leaving them exposed to greater tidal fluctuations and saltwater exposure.

Mangrove swamp is the dominant feature of the lower tidal reach and the embayment area. The dominant species are red mangrove, *Rhizophora mangle*, and white mangrove, *Laguncularia racemosa*. Black mangroves, *Avicennia germinans*, are occasionally found among white mangrove; however, they are more frequent along the Atlantic Intracoastal Waterway system. Presently, mangroves first appear as thin borders of vegetation along natural shorelines of the estuary and begin to occur as substantial "forest" at approximately RM 6.0 of the Northwest Fork of the Loxahatchee River. They are eventually replaced by the freshwater riverine floodplain community by RM 10.0.

Figure 3-10. An Example of Forest Type LTsw1 (Red Mangrove Swamp).

Figure 3-11. An Example of Forest Type LTsw2 (White Mangrove Swamp with Dead Bald Cypress).

Mangroves are very salt tolerant and tend to colonize shorelines where the substrate has been stabilized or protected from the effects of wave action or erosion. The continued spread of mangroves upstream in the river floodplain, displacing less salt tolerant species such as cypress and hardwoods, has been viewed as an impact to the ecosystem. These slow changes in river vegetation communities over time are linked to the combined effects of saltwater intrusion caused by permanent stabilization of Jupiter Inlet, dredging of the estuary, construction of C-18 Canal and reduced flows from the headwaters.

Even though the spread of mangroves into formerly freshwater environments is viewed as an adverse condition for the river, mangroves serve an important role in the estuary ecosystem, since these plants provide a stable substrate for many other species to colonize (Savage 1972). Mangroves are also a significant source of primary productivity and the physical and bacterial decomposition of mangrove leaf litter provides a major food source for detritivores in the estuary food chain (Heald and Odum 1970). Mangroves are susceptible to frost damage and may be highly impacted during a hard freeze.

Threatened or Endangered Plants

In addition to the dominant species used to define forest communities along the Northwest Fork of the Loxahatchee River State, many rare, endangered, or threatened plants also coexist in these communities. Within Jonathan Dickinson State Park alone, there are 29 plant species that are protected by the state or federal government. A list of protected plant species that occur within the Northwest Fork watershed are shown in **Table 3-3**.

Table 3-3. Threatened and Endangered Wetland Plant Species in the Loxahatchee River Watershed.

Scientific Name	Common Name	FCREPA[a]	FDA[b]	USFWS[c]
Actinostachys pennula	Fern ray/Tropical curly-grass fern		E	
Asclepias curtissii	Curtiss' milkweed		E	
Asimina tetramera	Four-petal pawpaw		E	E
Azolla caroliniana	Mosquito fern		T	
Bletia purpurea	Pine pink orchid		T	
Calopogon barbatus	Bearded grass pink		T	
Calopogon multiflorus	Many-flowered grass pink		E	
Campyloneurum latum	Strap fern		E	
Campyloneurum phyllitidus	Long strap fern		E	
Chamaesyce cumulicola	Sand dune spurge		E	
Chrysophyllum oliviforme	Satinleaf		E	
Cladonia perforata	Perforate reindeer lichen		E	E
Conradina grandiflora	Large-flowered rosemary		E	
Drosera intermedia	Water sundew		T	
Encyclia cochleata	Clamshell orchid		E	
Epidendrum rigidum	Rigid epidendrum		E	
Ernodea littoralis	Beach creeper		T	
Eulophia alta	Wild coco		T	
Habenaria nivea	Snowy orchid		T	
Halophila johnsonii	Johnson's seagrss			T
Lechea cernua	Nodding pinweed		T	

Scientific Name	Common Name	FCREPA[a]	FDA[b]	USFWS[c]
Lechea divaricata	Pine pinweed		E	
Lilium catesbaei	Catesby's lily		T	
Nemastylis floridana	Celestial lilt	T	E	
Nephrolepis biserrata	Giant sword fern		T	
Ophioglossum palmatum	Hand adder's tongue fern	E	E	
Peperomia humilis	Low peperomia		E	
Phlebodium aureum	Polyplody fern		T	
Pinguicula caerulea	Blue-flowered butterwort		T	
Pogonia ophioglossoides	Rose pogonia		T	
Polygala smallii	Small's milkwort		E	E
Psilotum nudum	Whisk fern		T	
Pteroglossaspis ecristata	Non-crested coco		T	
Sacoila lanceolata	Leafless red beak orchid		T	
Salvinia minima	Water spangles		T	
Spiranthes laciniata	Lace-lip ladies' tresses		T	
Spiranthes vernalis	Ladies' tresses		T	
Thelypteris interrupta	Aspidium fern		T	
Thelypteris kunthii	Aspidium fern		T	
Thelypteris palustris	Aspidium fern		T	
Thelypteris serrata	Dentate lattice vein fern		E	
Tillandsia balbisiana	Inflated wild pine		T	
Tillandsia fasciculata	Common wild pine		E	
Tillandsia flexuosa	Twisted air plant	T	E	
Tillandsia utriculata	Giant wild pine		E	
Tillandsia variabilis	Soft-leaved wild pine		T	
Tolumnia bahamensis	Dancing lady orchid		E	

Data from Treasure Coast Regional Planning Council (1999) and Jonathan Dickinson State Park Unit Management Plan, State of Florida Department of Environmental Protection (February 2000).

[a] Florida Committee on Rare and Endangered Plants and Animals.

[b] Florida Department of Agriculture and Consumer Services.

[c] United States Fish and Wildlife Service. E=Endangered, T=Threatened.

TRANSECT VEGETATION SUMMARIES

In the 2003 vegetation survey of the Northwest Fork of the Loxahatchee River, Transects #1, #2, #3, and #4 were examples of riverine forest types. Transects #6 and #7 were examples of the upper tidal reach and Transect #9 was an example of the lower tidal reach. The forest type of each $10m^2$ plot based on relative basal area is shown in **Appendix A**, while total number of canopy trunks by species by transect is shown in **Appendix B**. Survey profiles of each transect are illustrated in **Appendix C** and express elevation as feet NGVD29.

Riverine Transects

Transect #1 is located just downstream of Lainhart Dam at RM 14.5. This transect transverses the north and south sides of the Northwest Fork with 15 $10m^2$ plots (**Appendix A, Table 1A**). It has several elevation changes from 13.74 feet NGVD at the top of the mesic hammock to about 9.34 feet NGVD in the deeper swamp areas and 5.44 feet NGVD in the river channel (**Appendix C**). The exterior sides of Transect #1 are dominated by several plots of upland and hammock before dropping down into the floodplains as a cypress swamp (Rsw1) that borders the riverbed. One higher area adjacent to the bank of the river is classified as Rblh1 because red maple occurs within the plot and water hickory just outside of the measured plot. Cabbage palm, live oak (*Quercus virginiana*), and slash pine dominate the hammock and uplands plots while a stand of mostly very old bald cypress with an average dbh of 49 cm dominates the Rsw1 plots (**Appendix B**). The smallest bald cypress has a dbh of 9.9 cm. Because the canopy is well established and there are high flow velocities in this area, there is very little indication of a shrub layer and groundcover is probably seasonal in the swamp area. Also, there is no evidence of logging (i.e. stumps only) in this area. Shrubs and groundcover in the Rsw1 areas are dominated by swamp lily (*Crinum americanum*), tri-veined fern (*Thelypteris interrupta*) and downy shield fern (*Thelypteris dentata*). The exotic plants wild taro, *Colocasia esculenta*, and arrowhead vine, (*Syngonium podophyllum*), were also present as groundcover within the cypress swamp community.

Transect #2-1 is located at RM 13.6 just upstream of the western side of Masten Dam while Transect #2-2 is located downstream of Masten Dam (RM 13.4) on the same side of the river. There are several elevation changes between hammocks (approximately 9 feet to 11 feet NGVD), a very deep cut braided stream (6.32 feet NGVD), and the swamp areas (approximately 7.47 feet to 8.47 feet NGVD; **Appendix C**). Water appears to flow continuously through the cut, which is connected to the river above and below Masten Dam. Transect #2-2 has more hammocks (4 out of 6 plots) than does Transect #2-1 (3 out of 7 plots). Two and a half of the four plots on Transect #2-2 are mesic hammock and one half plot is hydric hammock (**Appendix A, Table 1B** and **Appendix B**). The mesic hammock is 100 percent cabbage palm. The Rsw1 and the Rmix plots are a little more diverse with younger pop ash, red maple and water hickory intermixed with the bald cypress. Bald cypress had an average dbh of 73.6 cm with the largest dbh at 114.5 cm while red maple and pop ash, average 23 cm and 9.7 cm, respectively. Also, there is one water hickory with a dbh of 9.2 cm. The smaller size of the red maple, pop ash and water hickory may indicate a trend towards subcanopy species that prefer shorter hydroperiods than bald cypress (**Figure 3-12**). The larger size of these bald cypress trees suggests that they may be several hundred years old, whereas the smaller red maple, pop ash, and water hickory may be no more than a few decades old (NPS 1984). This marked age difference may indicate that other deciduous tree species are taking advantage of the shortened hydroperiods experienced by the older bald cypress community during the last 50 years. Shrubs and groundcover are primarily tri-veined fern, Meniscium fern (*Thelypteris serrata*), leather fern, Virginia willow (*Itea* *virginica*), downy shield fern, royal fern (*Osmunda regalis*), lizard's tail (*Saururus cernus*), and swamp lily. Tri-veined fern, day flower (*Commelina diffusa)* and wild coffee (*Psychotria nervosa*, a hammock or uplands species) are prevalent in the Rlbh1 plot.

Transect #3 is located at RM 12.1 downstream of I-95 and the Florida Turnpike on the east side of the river. The site has been heavily impacted by selective logging in the past and by the presence of Old World climbing fern (*Lygodium microphyllum*). There are multiple braided streams within the floodplains at this site. Elevations range from 5.54 feet NGVD at the benchmark to 2.03 feet NGVD at the bottom of the braided streams, and -9.87 feet NGVD in the river channel (**Appendix C**). The majority of the floodplain has an elevation of approximately 4 feet NGVD in this area. Nine of the 13 plots are either Rsw1 or Rsw2 (**Appendix A, Table 1C**; **Appendix B**). Bottomland hardwood and hammock are present near the uplands and adjacent to the riverbed. Transect #3 has the highest concentration of pop ash of any of the 10 transects. The average dbh is 17 cm for pop ash; however, the range is 5 cm to 41 cm. Only 4 bald cypress trees are present within the transect canopy but they are very large with an average dbh of 91.5 cm. Pond apple and red maple trees are also present with an average dbh of 7.1 cm and 14.4 cm, respectively. Shrubs and groundcover on Transect #3 are primarily leather fern, maiden fern (*Thelypteris kunthii*), meniscium fern, and lizard's tail in the swamp, while tri-veined fern and swamp fern (*Blechnum serrulatum*) are the most prominent in the bottomland hardwood plots.

Transect #4 is located at RM 11.18 on the west side of the river approximately 1 mile upstream of Trapper Nelson's Interpretive Site. This transect is just downstream from an old logging road that crossed the floodplains and river. There are several elevation changes between the upland edge of the floodplain and the riverbed. The benchmark for this site is a very large dead pine tree, which is on the slope at about 5.62 feet NGVD. From the hammock the transect drops down into several Rsw1 plots intermixed with plots of Rlbh2 and Rlbh3 (**Appendix A**, **Table 1D**; **Appendix B**). Bottom elevations of the swamp plots are approximately 2.17 feet NGVD while the bottom of the river channel is -2.45 feet NGVD (**Appendix C**). Most of the plots closer to the river are bottomland hardwood with some of the largest water hickory observed in the watershed (**Figure 3-12**). Some of these large hickory trees exhibit the allelopathic nature of this species as little groundcover or shrubs are present beneath their canopy. Elevations of the Rlbh2 and Rlbh3 plots are approximately 2.51 feet to 3.91 feet NGVD. The average dbh of water hickory on the transect is 36.1 cm and with the largest at 88.6 cm. Bald cypress trees vary considerably in size and age across Transect #4. The average cypress dbh is 30.0 cm; but the dbh ranges from 5.7 cm to 83.6 cm indicating that several generations of trees are present. Pop ash and red maple averaged 12.2 cm and 11.0 cm dbh, respectively. Shrubs and groundcover are primarily leather fern, maiden fern, downy shield fern, Virginia willow, swamp fern, royal fern, lizard's tail, swamp lily and pond apple.

Figure 3-12. Water Hickory in Bottomland Hardwood Plot on Transect #4.

Evidence of plant species intrusion and displacement (i.e. a shift in plant species over time as hammock and upland species migrate into swamp areas) can be found throughout all of the riverine transects (**Figures 3-13** and **3-14**). **Figure 3-15** shows examples of displacement of plant species on Transect #4. The photograph (**Figure 3-12**) depicts an old water hickory (representative of the older community) surrounded by cabbage palms (*Sabal palmetto*), saw palmetto (*Serenoa repens*), and various ferns that would be more representative of hammock and upland communities. On Transects #1 and #2, slash pines *(Pinus elliotti)* were intruding into hammock areas while cabbage palms were displaced into swamp areas. Young red maple (*Acer rubrum*) were displaced from bottomland hardwood areas into swamp areas. Transect #3, also had cabbage palm displaced to bottomland hardwood and swamp areas along with wild coffee (*Psychotria* sp.*)* and myrtle oak (*Quercus myrtlifolia)*. Brazilian pepper (*Schinus terebinthifolius*) which is normally an upland species had invaded bottomland hardwood and swamp communities of Transects #3 and #4.

Historical inundation analysis revealed that the riverine floodplain was unavailable for fish and aquatic wildlife utilization about 75 percent of the time for most years because of the lack of sufficient floodplain inundation. The need for baseline field monitoring and the plan for study are outlined in **Chapter 10** (Ecological Monitoring for Adaptive Management). A more natural hydroperiod in the riverine floodplains would potentially increase food resource availability (i.e. invertebrates, amphibians, fish and birds) and provide a multitude of aquatic habitats. Amphibians in particular are important indicators of ecological health because they require out of channel aquatic habitat to breed successfully. South Florida amphibians need various lengths of continuous inundation for the metamorphosis from larvae to adult (**Table 10-2**). Larval and juvenile riverine fishes utilize the shallow floodplain habitat to hide from larger predators. Depending upon water depth, fishes of all sizes migrate into the floodplains and use the vast plant and invertebrate food resources. Several recent publications have illustrated the significance of submerged snags as habitat to increase invertebrate populations, which also increases food resources for several other biological communities. Benke (2001) found that benthic invertebrate assemblages in the floodplains of the Ogeechee River (Georgia) were different from both snags and benthos of the main channel. Benke also indicated that the regular exchange of water, nutrients and other organic matter between the river channel and floodplain was a critical connection. These factors support the need to provide additional floodplain inundation on the riverine floodplains and within the river channel of the Loxahatchee River and its major tributaries.

In summary, the riverine floodplain of the Northwest Fork of the Loxahatchee River can be enhanced by sufficient floodplain inundation to discourage the intrusion of transitional, upland, and exotics plant species and to increase utilization of the floodplain by aquatic organisms. Recent river restoration studies in regulated systems such as the Loxahatchee River (Poff et al. 1997; Toth et al. 1998; and Benke 2001) have emphasized the importance of establishing the needed flow regimens, rather than just providing minimum flows. Thus, providing additional freshwater flow over Lainhart Dam will improve seasonal hydroperiod and will subsequently improve plant community health and enhance the riverine floodplain ecosystem. Recommendations for hydroperiod requirements of hydric hammock and floodplain swamp communities are presented in **Chapter 4**.

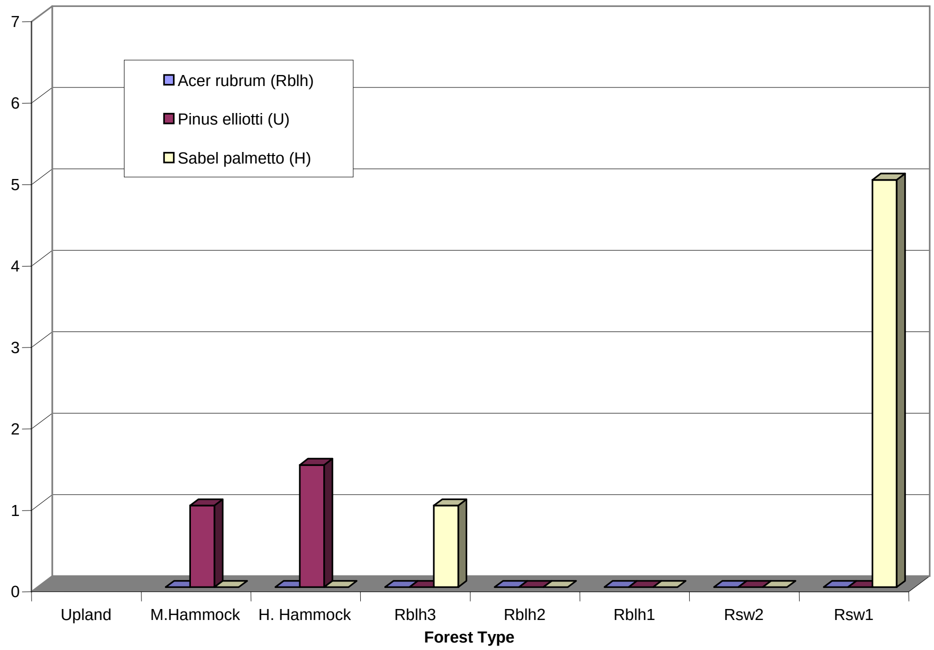

Figure 3-13. Frequency of Occurrence: Displaced & Intrusive Canopy & Shrub Species-Transect # 1

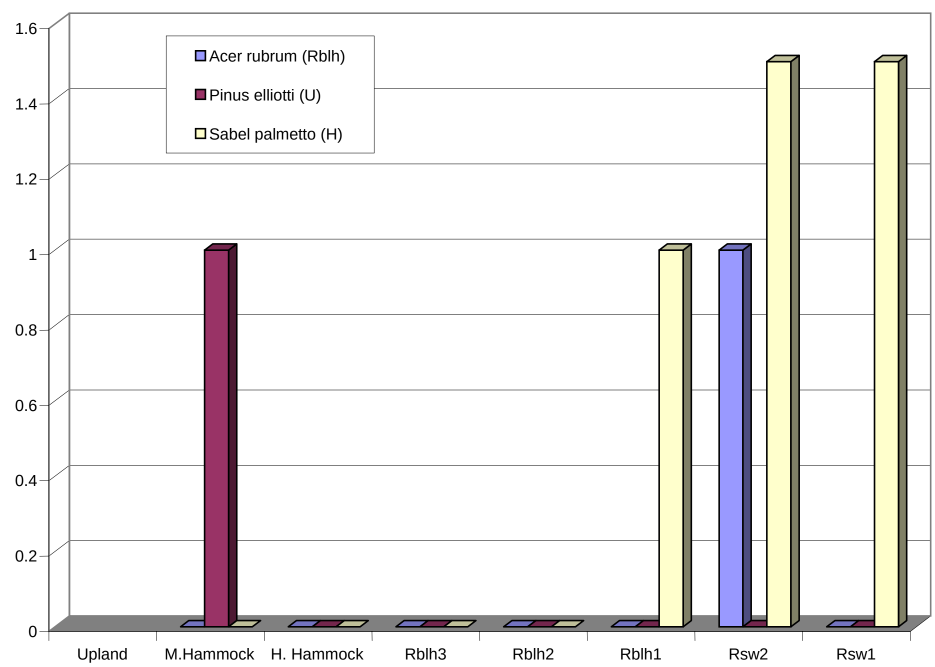

Figure 3-14. Frequency of Occurrence: Displaced & Intrusive Canopy & Shrub Species-Transect #2.

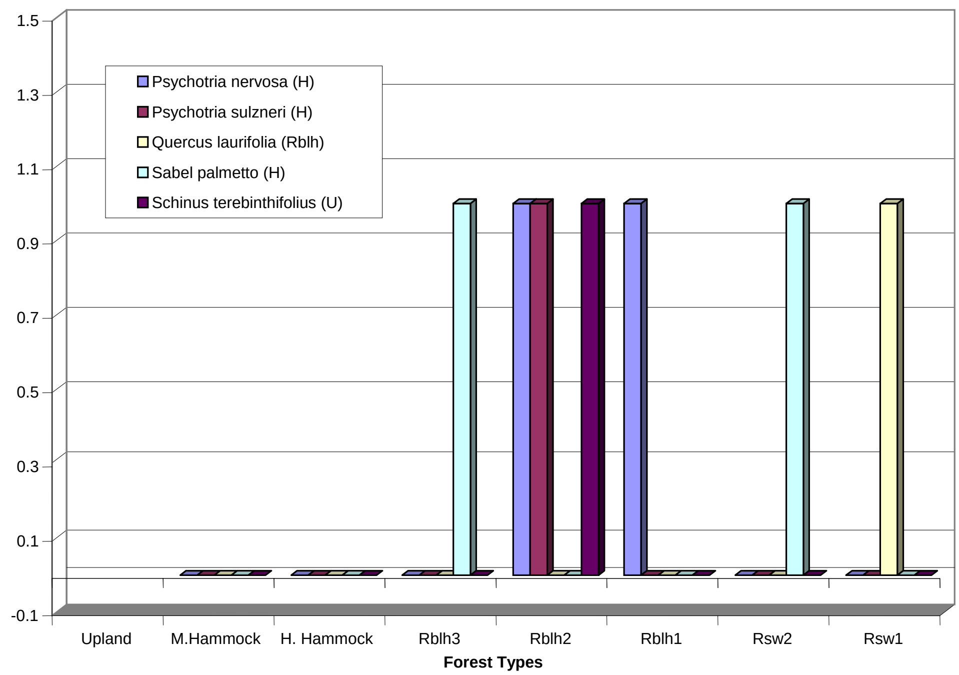

Figure 3-15. Frequency of Occurrence: Displaced & Intrusive Canopy & Shrub Species-Transect #4.

Tidal Transects

Of the three tidal transects on the Northwest Fork of the Loxahatchee River, two sites are upper tidal (Transects #7 at RM 9.1 and #6 at RM 8.4) and one site is lower tidal (Transect #9 at RM 6.46). The elevations of these transects are generally lower, more gently sloping towards the river, and have fewer braided streams than those transects in the riverine reach. There were no bottomland hardwood plots in the tidal reaches although indicator species for these forest types are present. In the tidal reaches, canopy diversity is increased by the presence of hummocks (i.e. elevated mounds), cypress stumps, and fallen logs. Hummocks allow canopy species that would not normally be present in swamp communities to successfully occupy areas of lower elevation (**Figure 3-16**). Forest types in the tidal reaches are generally mixtures of swamp species (fresh and brackish water species), and mixtures of swamp, hammock, and upland species. Based on historical records and aerial photography, the most abundant vegetative species in the tidal reaches of the Northwest Fork of the Loxahatchee River were bald cypress and cabbage palm. Based on a 1860s military drawing of the Northwest Fork, the only passage upstream of the mouth of Kitching Creek was by canoe. Today the river is navigable by boat for an additional 2.2 miles upstream from Kitching Creek. Saltwater intrusion, rising sea levels, lowered groundwater levels, and decreasing freshwater flows have resulted in the increase in the distribution of red and white mangroves throughout the tidal reaches. In addition, historical logging, fire, freezes, exotic plants (Old World climbing fern, Brazilian pepper, java plum and strawberry guava), and erosion of the river channel have impacted sections of our tidal transects.

Figure 3-16. Cabbage Palm Utilizing a Hummock Among Red Mangroves and Pond Apples (UTsw1) on Transect #6.

Transect #6 is located at RM 8.4 on a peninsula just upstream of Kitching Creek and adjacent to National Audubon's Ornamental Garden (Kitching Creek Sanctuary). This peninsula has been selectively logged in the past and contains the remnants of many dead cypress trees. Today, there are still live cypress trees growing among the pond apples and mangroves and a band of cypress trees still exist adjacent to the uplands. Elevations range from 6.82 feet NGVD in the uplands to an average elevation of 1.59 feet NGVD over the remaining length of the transect (**Appendix C**). Of the 16 plots on Transect #6, there are 2 Upland, 1 Rsw1, 6 UTsw1, 6 UTsw3, and 1 UTmix plots (**Appendix A, Table 1E**). The most prevalent species are red and white mangrove and pond apple with an average dbh of 8.3 cm (**Appendix B**). Red maple (dbh 17.5 cm) and pop ash (average dbh 5.7 cm) are present in much smaller numbers. The average dbh of the living bald cypress trees is 29.8 cm. Approximately 85 meters from the uplands on Transect #6, there is a large, healthy bald cypress tree totally surrounded by red mangroves. Red mangrove and pond apple are more prevalent in the plots beyond 110 meters from the uplands, which demonstrates the significance of floodplain topography in species distribution. Shrubs and groundcover consist primarily of very young red and white mangrove, leather fern, pond apple, buttonbush, maiden fern, swamp fern, and rubber vine (*Rhabdadenia biflora*).

Transect #7 is located at RM 9.1 on the south side of the mid Northwest Fork across from the eastern end of Hobe Grove Ditch. This transect has been impacted by saltwater intrusion, exotic vegetation (mostly Old World climbing fern, Brazilian pepper, and java plum) and logging. It is a very long transect with 15 plots that contain a mixture of 8 riverine and 7 upper tidal forest type plots (**Appendix A, Table 1F**, and **Appendix B**). Elevations change from 10.06 feet NGVD at the benchmark to an average of 1.58 feet NGVD across most of the floodplain (**Appendix C**). The riverine section of the transect consists of a mixed plot (Hammock/Rsw1) with live oak, wax myrtle, and a large cypress (50.1 cm dbh) followed by 2 plots of Rsw1, and 5 plots of Rmix (primarily bald cypress, cabbage palm and wax myrtle). Cabbage palm and wax myrtle coexist with the swamp species by living on small hummocks, old logged cypress stumps, and other fallen logs. The Upper Tidal segment of Transect #7 has 4 plots of UTsw1 and 3 plots of UTsw2. At a distance of 120 m from the upland, red mangroves begin to appear and become more abundant along with pond apples. White mangroves are present but were too small to be considered canopy (i.e. dbh <5 cm). Live bald cypress trees are present from the edge of the uplands out to 120 m of the 150-meter transect. The bald cypress trees have an average dbh of 28.3 cm and range from 7.2 cm to 50.1 cm dbh. Shrubs and ground cover consist primarily of leather fern, wax myrtle, buttonbush, salt bush, primrose willow, poison ivy, swamp fern, marsh fern, meniscium fern, royal fern, swamp lily, milk vine, and young mangroves, pond apples and pop ash. The riverine plots appear to have muck soils while the upper tidal plots appear to have sandy soils.

In the late fall of 2003, Transect #7 had an extremely large number of cypress seedlings ranging from 5 cm to 7.6 cm in height. Germination of new seedlings continued well into the late spring. The dry season (December 2003 to May 2004) was very dry. Tides did not reach the entire transect during this period and the rains did not come until mid-July 2004. This dry period may have been advantageous for germination and early bald cypress seedling growth. During a visit in 2003, U.S.G.S. botanists, Helen Light and Melanie Darst, suggested that perhaps the stress of the salt may have made the trees more reproductively active. They also noted that the bald cypress trees on this site were probably younger than their counterparts in the riverine reaches of the river. Also in the riverine portion of the river, the cypress tree canopy was much taller and thicker. Therefore, less light maybe available for the development of an extensive subcanopy in the riverine reach. Duever et al. (1983) suggest that a good recruitment season for bald cypress may take place every 30 to 40 years. During a visit to Transect #7 in August 2004, many of the fall 2003 bald cypress seedlings were gone. Daily tides had returned to the interior of the transect. Seedling death may have occurred because the seedlings were too short to survive the periods of tidal flooding (twice a day) or because of increased salinity. Some of these questions will be answered by the ongoing bald cypress seedling study.

Transect #9 is located at RM 6.5 on a peninsula near the Jonathan Dickinson State Park (JDSP; **Figure 3-17**). The hydrology of the floodplain in this area has been impacted by the placement of an elevated trail that circles the peninsula. During extreme high tides, the trail acts as a barrier and traps saltwater in the wetland system. Elevations across Transect #9 range from 9.48 feet NGVD at the benchmark to a very low area (1.31 feet NGVD) located adjacent to the river (**Appendix C**). Between 50 and 70 meters from the upland a quite pronounced hammock area exists. Elevations in the hammock range from 1.95 feet NGVD to 2.05 feet NGVD and along the trail are 2.01 feet NGVD; the remaining areas in the floodplain are approximately 1.63 feet NGVD. Of the 20 plots on this transect, 17 are lower tidal swamp (LTsw1 and LTsw2, **Appendix A, Table 1G**). The other 3 plots are upland, hammock, and LTmixed. The most prevalent species in the canopy, shrub and groundcover layers are red and white mangroves in the swamp areas and cabbage palm in the hammock areas (**Appendix B**). Pond apples in the canopy are rare; they are found predominately in the deeper swamp area at the back of the floodplains and had an average dbh of 7.2 cm. There is a noticeable difference between the distribution of red and white mangroves. White mangroves are dominant from the toe of the slope out to approximately 160 m. The remaining four plots (160 m to 200 m) are dominated by red mangrove. Leather fern dominates the shrub layer while water hyssop, leather fern and rubber vine dominate the groundcover. During a visit in August 2004, it was noted that the majority of the cabbage palms that had been recorded as alive in 2003 were now dead. The only cabbage palms remaining alive were associated with the trail and the hammock areas.

Historically, the canopy on Transect #9 was dominated by bald cypress trees; however, most of these trees are now dead. In his 1967 plant survey of this transect, Taylor Alexander reported live bald cypress at a frequency of 22.2 and a density of 0.39 (14 live and 28 dead). Red and white mangroves were at a frequency and density of 52.8/1.31 and 36.1/2.64 (47 red and 95 white). Alexander also reported the presence of several other freshwater species in small numbers including sawgrass (*Cladium jamaicense*), swamp lily, red bay, pop ash, red maple, and buttonbush. In a 1975 JDSP survey of 100 bald cypress trees on the peninsula, 71 were dead, 21 were healthy and 8 were stressed. In our 2003 survey, there were no live cypress within Transect #9 and red and white mangroves were at a frequency and density of 47/5.79 and 100/12.32. In an April 2004 re-survey of bald cypress trees on the peninsula, 151 were dead, 7 were stressed and 3 were living. The three living bald cypress trees are directly adjacent to or on the trail.

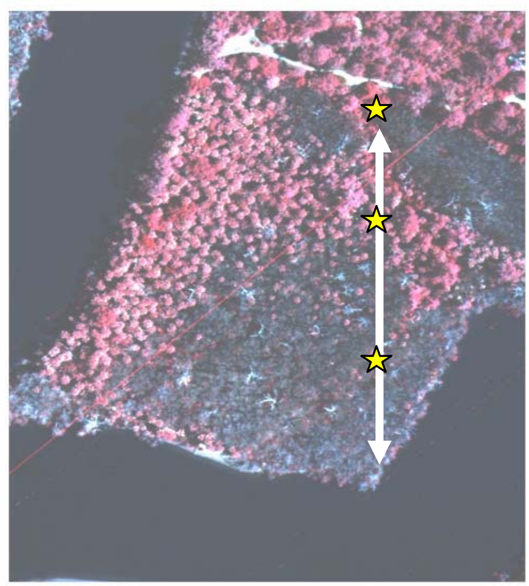

Figure 3-17. Location of Transect #9 on a Peninsula Near Jonathan Dickinson State Park (JDSP).

ANIMALS

The expansiveness and diversity of habitats occurring in or adjacent to the Loxahatchee River has attracted and continues to support many species of native animals. In 1965, 267 species of animals, consisting of 169 genera and 78 families, were observed in and along the Loxahatchee River and its estuary. The area surrounding the Northwest Fork is inhabited by numerous vertebrate species identified as endangered, threatened or of special concern by the Florida Fish and Wildlife Conservation Commission, or listed as threatened or endangered by the U.S. Fish and Wildlife Service. State and federally listed animals that occur in the watershed are shown in **Table 3-4**.

In addition, the entire Loxahatchee River has been designated by the U.S. Fish and Wildlife Service as a critical habitat for the West Indian manatee (1996). The manatee, an endangered aquatic mammal, frequents the Loxahatchee River and Estuary. Invertebrate and vertebrate aquatic animals are numerous in the marshes, lakes and streams in the river area. Freshwater fish include largemouth bass, speckled perch, bluegill, shellcracker, redbreast, warmouth, bowfin, gar, channel catfish and many species of minnows. Numerous turtles also live in and around the river. Saltwater fish include snook, tarpon, mullet, bluefish, jack, sheepshead, drum, sand perch, grouper, snapper and flounder. Mammals and birds are frequently encountered along the riverbank. The more commonly seen species include raccoon, opossum, whitetail deer, osprey, barred owl, egrets, herons and ibis.

Nuisance species include the Cuban treefrog (*Osteopilus septentrionalis*) and feral hog (*Sus scrofa*). The Cuban treefrog was limited to the Florida Keys and Miami-Dade County until the late 1960s. Since then, it has spread rapidly northward and has been reported north of St. Petersburg. The adult Cuban tree frog is larger than any other native tree frog in Florida and unfortunately readily eats the smaller native frogs. Feral hogs have spread widely across North America since their first introduction by DeSoto in 1539. They adversely impact the environment and agriculture through habitat degradation, predation competition on native species, and transmission of diseases to livestock and humans. In 2001, swine control assessments were conducted within Jonathan Dickinson State Park to gather information on abundance and distribution (Engeman et al. 2001). Although the swine control program reduced fresh damage indices, re-invasion was evident. Both Cuban tree frogs and feral hogs were evident on most of the vegetative transects.

Additional species, although not identified on the official lists compiled by the State of Florida, may be identified as being either endangered, threatened or of special concern by the Florida Committee on Rare and Endangered Plants and Animals. The threatened osprey often nests in dead cypress trees in the lower Northwest Fork. The great egret, the black-crowned night heron and the yellow-crowned night heron, classified as Species of Special Concern, are also found in the Loxahatchee River Watershed.

The federally designated National Wild and Scenic portion of the Northwest Fork of the Loxahatchee River, a major part of which is located within Jonathan Dickinson State Park, contains 52 federal and state species that are endangered, threatened, or of special concern (23 animals and 29 plants). Those species having a federal designation found within this area include the alligator, indigo snake, scrub jay, bald eagle, wood stork, snail kite, manatee, four-petal paw paw, perforate lichen and Small's milkwort (FDEP 1998).

Table 3-4. Threatened and Endangered Animals and Species of Special Concern in the Loxahatchee River Watershed.

Scientific Name	Common Name	FCREP[a]	FGFWFC[b]	USFWS[c]
FISH				
Centropomus undecimalis	Common snook		SSC	
AMPHIBIANS				
Rana capito aesopus	Gopher frog	T	SSC	
REPTILES				
Alligator mississippiensis	American alligator	SSC	SSC	T(S/A)
Drymarchon corais couperi	Eastern indigo snake	SSC	T	T
Gopherus polyphemus	Gopher tortoise	T	SSC	
Pituophis melanoleucus	Florida pine snake		SSC	
BIRDS				
Ajaia ajaja	Roseate spoonbill	R	SSC	
Aphelocoma coerulescens	Florida scrub jay	T	T	T
Aramus guarauna	Limpkin	SSC	SSC	
Dendroica kirtlandii	Kirtland's warbler	E	E	E
Egretta caerulea	Little blue heron	SSC	SSC	
Egretta thula	Snowy egret	SSC	SSC	
Egretta tricolor	Tricolored heron	SSC	SSC	
Eudocimus albus	White ibis	SSC	SSC	
Falco pergrinus tundrius	Arctic peregrine falcon	E	E	
Grus canadensis pratensis	Florida sandhill crane	T	T	
Haliaeetus leucocephalus	Bald eagle	T	T	T
Mycteria americana	Wood stork	E	E	E
Pelecanus occidentalis	Brown pelican		SSC	
Picoides borealis	Red-cockaded woodpecker	E	T	E
Polyborus plancus audubonii	Crested caracara		T	T
Rostrhamus sociabilis	Snail kite	E	E	E
Speotyto cunicularia floridana	Florida burrowing owl	SSC	SSC	
Sterna antillarum	Least tern	T	T	
MAMMALS				
Peromyscus floridanus	Florida mouse	T	SSC	
Sciurus niger shermanii	Sherman's fox squirrel	T	SSC	
Trichechus manatus latirostris	West Indian manatee	T	E	E

Data from Treasure Coast Regional Planning Council (1999) and Jonathan Dickinson State Park Unit Management Plan, State of Florida Department of Environmental Protection (February 2000).
[a] Florida Committee on Rare and Endangered Plants and Animals.
[b] Florida Game and Freshwater Fish Commission.
[c] United States Fish and Wildlife Service.
E=Endangered, R=Rare, T=Threatened, T(S/A)=Threatened/Similarity of Appearance, SSC=Species of Special Concern.

THE ESTUARINE ECOSYSTEM

Biological resources of the Loxahatchee River Estuary are greatly affected by freshwater flows, tidal flows, and human activities. Many freshwater and marine organisms are dependent on certain ranges of salinity within the estuary in relation to habitat at different times of their life cycle. This dependence on salinity has lead to many salinity classification systems based on species distribution. In general, however, oligohaline waters are low salinity (0.5-5 ppt), mesohaline waters are intermediate salinity (5-18 ppt) and polyhaline waters have high salinity (18-30 ppt). In many south Florida estuarine environments, mangroves, oysters and seagrasses form the bases of major biological communities that may be related to these salinity ranges where federally threatened species find refuge. Therefore, it is important that any proposed flow regime be sensitive to the salinity needs of flora and fauna that depend on the estuary.

OLIGOHALINE ECOZONE – FISH LARVAE

One of the important ecological functions of an estuary is the utilization of the low salinity zone (LSZ) at the head of the estuary. The LSZ serves as a nursery for larval and juvenile life stages of many important fish and shellfish (Pearse and Gunter 1957; Gunter 1961; Day et al. 1989). This critical habitat receives eggs, larvae and young from anadromous and catadromous fish and shellfish, estuarine spawners, and larvae spawned in the more saline lower estuary and ocean (Day et al. 1989). The relative magnitude of successful larval development and survival in the LSZ may be reflected in the magnitude of recruitment into the adult population (North and Houde 2001).

The LSZ salinity range is typically defined as 0.5 to 5.0 ppt (oligohaline). However, this Restoration Plan will extend the LSR to 10 ppt since it has been demonstrated that this range is appropriate for studying fish larvae in an estuarine system (Holmes et al. 2000; North and Houde 2001) and is often associated with the maximum turbidity known as the turbidity maximum (Jassby et al. 1995; North and Houde 2001). Although salinity is not the only important variable defining the spatial extent of the LSZ nursery, salinity may act as a proxy variable for habitat characteristics which covary with salinity. The spatial extent of the LSZ in the Loxahatchee Estuary will be defined as the area upstream of the 10 ppt isohaline.

In general, the open waterway within the LSZ nursery area is an essential habitat for fish and shellfish larvae while the shallow shoreline and tributaries provide essential habitat for the juvenile fish and shellfish. **Table 3-5** lists the surface area of the Loxahatchee Estuary (in acres) and the length of shoreline (in feet) by River Mile segment. As the base flow increases, the cumulative area of waterway and cumulative length of shoreline of the LSZ habitat also increases. More detailed information will define the affects of different low-flow scenarios on the location and quantity of maximum turbidity in relation to larval utilization. The quality of LSZ shoreline may provide a more detailed evaluation of this habitat than the amount of habitat alone. For example, a shoreline composed of red mangroves acts as an important ecotone between the waterway and the floodplain wetlands and may have more habitat value than a seawall shoreline. A red mangrove shoreline with a shallow tributary may have even more habitat value than the mangrove shoreline alone. **Figure 3-6** shows the distribution of red mangroves and tributaries.

Table 3-5. Surface Area and Length of the Loxahatchee Estuary Oligohaline (Low Salinity Zone) Ecozone from River Miles 4.0 to 10.5.

River Mile Segment	Area (Acres)	Cumulative Area (Acres)	Shoreline (ft)	Cumulative Shoreline (ft)
10.5 to 10	6.3	6.3	12,861	12,861
10 to 9	12.7	19.0	18,095	30,956
9 to 8	24.3	43.3	31,292	62,248
8 to 7	28.6	71.9	16,086	78,334
7 to 6	30.7	102.6	14,501	92,835
6 to 5	88.8	191.4	59,210	152,045
5 to 4	--	--	37,119	189,164

MESOHALINE ECOZONE - OYSTERS

Estuarine areas with salinities between 5 and 18 ppt are defined as mesohaline regions. Most of the oyster community is found in this salinity range and is sensitive to changes in flow regimes.

Oyster bars are important habitat providing extensive attachment areas for many organisms including oyster spat, mussels, tunicates, bryozoans, and barnacles (Woodward-Clyde International Americas 1998). Oysters also play an important role in the estuarine food chain. Free-swimming oyster larvae are heavily preyed upon by planktivores, such as ctenophores, anemones, and larval fishes; and oyster spat are eaten by carnivorous worms and small crabs such as mud and juvenile blue crabs (Woodward-Clyde International Americas 1998). Larger oyster spat and small adult oysters are consumed by blue crabs, stone crabs, whelks, conchs, oyster drills, boring clams, boring sponges, skates, rays and fishes such as black drum and redfish (Wells 1961).

Salinity affects oyster reproduction, growth and distribution. Oyster spawning depends on salinities greater than 7.5 ppt and spat grow best at salinities above 12.5 ppt; the optimum salinity range for adult oysters is from 10 ppt to 28 ppt. The lower salinities in this range exclude marine predators (Sellers and Stanley 1984). In 1990 the oyster reefs were present in the Southwest and Northwest Forks but were rare in the North Fork of the Loxahatchee Estuary. Oysters in the embayment area were small in the polyhaline region and limited to isolated shell clusters and accumulations on dock pilings. Numerous relict shells in the embayment were associated with shoals, point-bars and mangrove islands (Law Environmental, Inc. 1991a). Field observations revealed oysters were smallest at the upstream (RM 6) and downstream embayment locations and largest in the central part of their range near RM 4.2. The largest populations of oyster grow in intertidal and shallow subtidal areas near shorelines upstream of the Northwest Fork River delta (RM 4.2) to about RM 6. The river delta (“S-Bar”) provides a significant barrier to tidal flow and therefore tends to greatly influence salinity. Favorable salinities near and upstream of this location results in dense and large oysters. These waters are designated Class II; Shellfish Propagation and Harvesting by the FDEP.

POLYHALINE ECOZONE - SEAGRASSES

Estuarine areas with salinities between 18 ppt and 30 ppt are defined as polyhaline regions. For this Restoration Plan, the section of the Loxahatchee River Estuary from the Jupiter Inlet (RM 0.0), through the Central Embayment (RM 2.0), to RM 4.0 is considered to be within the polyhaline ecozone. Seagrass beds are key biological communities in the Loxahatchee Estuary and could potentially be impacted by upstream restoration activities.

Seagrass beds are one of the most productive and important estuarine communities. They provide food for bacteria and microscopic animals at the base of a complex food web, as well as, food for larger organisms such as green sea turtles (*Chelonia mydas*) and manatees (*Trichecus manatus*). Seagrass beds offer a refuge and nursery ground for numerous commercially and recreationally valuable shrimp, fishes and crabs and their prey (Zieman 1982; Phillips 1984; Thayer et al. 1984; Kenworthy et al. 1988; Zieman and Zieman 1989).

Wading birds frequent seagrass beds at low tides to feed on fish that use the seagrass canopy and root/rhizome mat for shelter (Sogard et al. 1989). Migratory waterfowl and diving birds also regularly feed in and over seagrass beds. Some of the invertebrate fauna associated with seagrass beds include gastropods, star fishes, sea urchins, sea cucumbers, pink shrimp, and spiny lobsters. Seagrass beds are visited or inhabited by numerous fish species. They provide nursery habitat for recreationally and commercially important drums (Sciaenidae), sea bass (Serranidae), porgies (Sparidae), grunts (Pomadasyidae), snappers (Lutjanidae), and mojarras (Gerridae) (Odum and McIvor 1991).

Seagrass beds are also known to enhance water quality. They bind shallow underwater sediments with their roots and rhizomes. The leafy canopy baffles waves and currents (Fonseca et al. 1983; Fonseca and Fisher 1986; Fonseca 1989; Fonseca and Cahalan 1992). The baffling inhibits resuspension of fine particles and traps sediments in the water column, providing water column cleansing (Ward et al. 1984). Additionally, seagrasses and associated epiphytes and macroalgae take up dissolved nutrients.

It is generally accepted that if healthy seagrass beds are present, then a diverse and productive faunal community will also be present. Biological productivity and diversity in many estuarine systems is dependent upon healthy seagrass beds. Numerous studies have shown high densities and diversities of animals occur in seagrass beds (Gilmore 1995; Lewis 1984; Thayer et al. 1984; Virnstein et al. 1983).

All seven seagrass species that occur in South Florida are found within the Loxahatchee Estuary. Six species of seagrasses are currently found in the polyhaline region of the estuary. The seventh species, widgeon grass (*Ruppia maritima*), is present upstream in the oligohaline region near RM 6.5 (Loxahatchee River District 2004). The six species of seagrass found within the polyhaline region are shoal grass (*Halodule wrightii),* manatee grass *(Syringodium filiforme)*, turtle grass *(Thalassia testudinum),* paddle grass (*Halophila decipiens*), star grass *(Halophila engelmannii),* and Johnson's seagrass *(Halophila johnsonii).* The dominant seagrass species present in the polyhaline region of the estuary is shoal grass.

Restoration efforts will change the freshwater flows to the Northwest Fork of the Loxahatchee River and may potentially impact the salinity regime in the estuary. An understanding of the salinity tolerances of the seagrass species within the estuary is needed to help evaluate potential impacts of proposed upstream restoration efforts on the downstream resources.

A literature review was conducted for the SFWMD to evaluate salinity tolerances of seagrasses found in the St. Lucie Estuary (Woodward-Clyde International 1998). Although none of the published studies were conducted on plants from the Loxahatchee Estuary, the studies did include all of the species found in the Loxahatchee River. These species-specific tolerance values will provide the basis for the Loxahatchee seagrass/salinity evaluations presented in this plan.

The literature provides normal and optimal salinity tolerance ranges for all seven seagrass species. Widgeon grass and shoal grass have the widest salinity tolerance ranges: 0 ppt to 45 ppt and 5 ppt to 55 ppt, respectively. Optimal (no stress) conditions for growth and survival apparently occur between 5 ppt to 15 ppt for widgeon grass and between 24 ppt to 36 ppt for shoal grass. More narrow salinity tolerance ranges are reported for turtle grass (16 ppt-50 ppt) and manatee grass (17 ppt-44 ppt). The optimal ranges suggested for these two species are 25 ppt to 35 ppt for turtle grass and 24 ppt to 36 ppt for manatee grass.

The three *Halophila* species have the least well-documented salinity ranges of the seven seagrass species found in the Loxahatchee River, but based on information provided in the literature review, the following normal tolerance ranges are reported: paddle grass (22 ppt – 38 ppt), star grass (10 ppt - 40 ppt), and Johnson’s seagrass (15 ppt - 43 ppt). The optimal salinity conditions reported for the species are paddle grass (27 ppt-34 ppt), star grass (25 ppt-35 ppt), and Johnson’s seagrass (25 ppt-35 ppt).

Additional studies were reviewed that identified salinity ranges that may cause stress (reduced growth or increased mortality) to four of the seagrass species found in the Loxahatchee Estuary. For shoal grass, Doering et al. (2002) showed that very little growth occurred between 6 ppt and 12 ppt. Another study (McMahan 1968) indicated that blade mortality occurred in shoal grass below 6 ppt. Two other laboratory studies documented negative impacts to manatee grass at 15 ppt. In one experiment, blade densities decreased when plants were exposed to 15 ppt for 26 days (SFWMD 1999 unpublished). In another experiment leaf extension rates decreased in plants exposed to 15 ppt for 14 days (Lirman and Cropper 2003). Studies of turtle grass found limited growth between 16 ppt and 19 ppt and a decrease in photosynthesis at 18 ppt (Woodward-Clyde 1998). Doering and Chamberlain (2000) found growth parameters in turtle grass were negatively impacted between 6 ppt and 12 ppt. Finally, although very little salinity tolerance information is available for the *Halophila* species, Dawes et al. (1989) reported blade mortality when Johnson’s seagrass was exposed to 5 ppt for 3 days.

Johnson’s seagrass occurs throughout the polyhaline region of the Loxahatchee Estuary (Loxahatchee River District 2004). It is the only seagrass species listed as “threatened” by the Federal Government. Johnson’s seagrass is listed as “threatened” because of its limited geographic distribution; it has only been found along the Florida east coast from Sebastian Inlet to northern Biscayne Bay. On April 5, 2000 (65 Federal Register 17786), the National Marine Fisheries Service (NMFS) published a final rule designating critical habitat for Johnson's seagrass. One of 10 sites identified as critical habitat is located near the Jupiter Inlet in the Loxahatchee Estuary (**Figure 3-18**). The designation as “critical habitat” means that the Federal government has determined that the designated area is vital to the conservation of the listed species. Any proposals to alter flow conditions in the Northwest Fork to the extent that they may impact the local population of Johnson’s seagrass will have to be reviewed and approved by the NMFS.

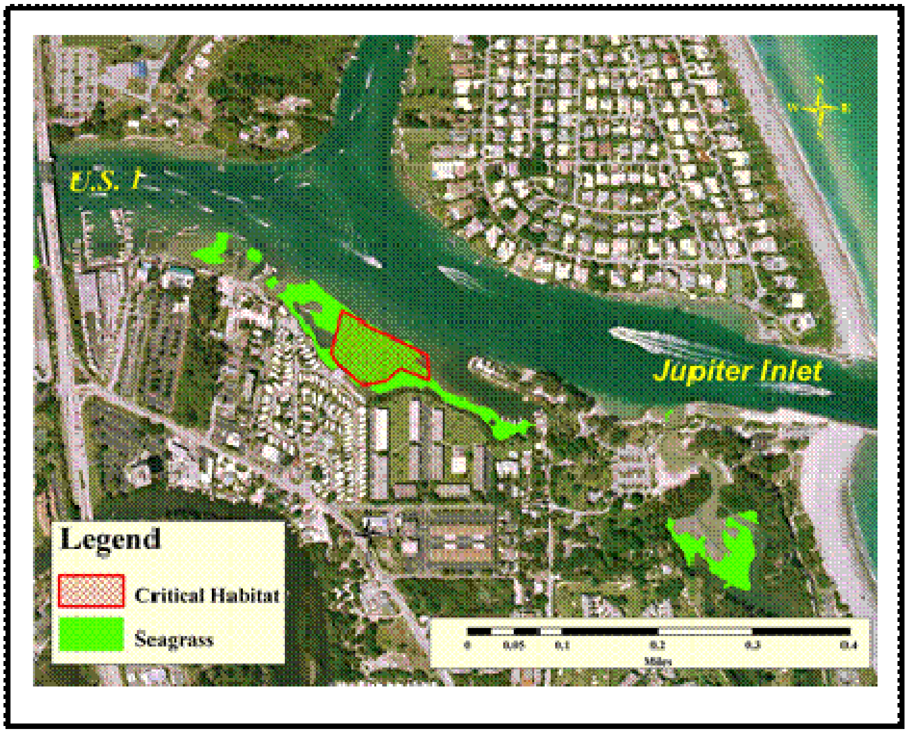

Figure 3-18. Critical Habitat for Johnson's Seagrass within the Loxahatchee Estuary.

Another Federally listed species that occurs within the Loxahatchee Estuary is the West Indian manatee, *Trichechus manatus*. This endangered species feeds on seagrasses and frequents the Loxahatchee Estuary. Changes in freshwater flow could potentially contribute to changes in distribution or abundance of seagrass which could impact this endangered species. As with Johnson's seagrass, any proposed flow modifications that could potentially impact endangered species will have to be reviewed and approved by the NMFS.

BENTHIC MACROFAUNA

Benthic organisms are important as consumers of plankton and detritus in filtering the water column, and as food for bottom-feeding fish. Benthic macroinvertebrates are sensitive to subtle changes in water quality. The diversity and abundance of these organisms in the ecosystem make them good biological markers for investigating long-term changes in this estuarine environment. Unlike plankton or fishes, their limited mobility makes them reliable indicators of the overall health of a system.

Various surveys of macrofauna have been conducted in the Loxahatchee Estuary (McPherson et al. 1984; Strom and Rudolph 1990; Law Environmental, Inc. 1991a; Dent et al. 1998). McPherson et al. (1984) studied fouling organisms in the Loxahatchee Estuary and noted that two of eight barnacle species occurred only in marine salinities, while other species occurred in lower salinities. Only one species occurred as far upstream as the JDSP. The overall diversity, density and growth of fouling communities are greater in high salinity areas, greater before the summer-wet season and higher after tropical storms. Strom and Rudolph (1990) observed that representatives of brackish water fauna occurred as far upstream as the Trapper Nelson site (RM 10.5), although most of the species at this location were typical of freshwater environments.

Samples collected by Law Environmental, Inc. (1991a) from oyster reef communities in the estuary contained representatives of 41 invertebrate taxa from seven phyla. Analyses of these data indicated that four taxa had broad distributions along the river and occurred upriver to the limit of their survey within JDSP. Almost a third of the taxa were marine species, requiring high salinities that occurred no farther upstream than the oyster reef at the mouth of the Southwest Fork.

The Wildpine Ecological Laboratory, which is operated by Loxahatchee River District, performed quantitative infaunal sampling at nine estuarine stations between 1992 and 1999. Sampling occurred twice a year, once during the dry season (February-March) and once during the wet season (September-November). The locations of five of the nine estuarine stations are presented in **Figure 3-19**. Preliminary results (Dent et al. 1998) found 410 invertebrate species in the estuary and adjacent waters. Overall, the five estuarine stations sampled contained fewer taxa than the four stations located in more marine waters. Estuarine stations contained a larger proportion of crustaceans (44%) than annelids (33%) or mollusks (11%), whereas stations in more marine waters contained a predominance of annelids (58%), about 30 percent crustaceans and 7 percent mollusks. Initial analyses of these data and comparisons with data from other studies suggest that this estuarine invertebrate community shows seasonal changes in species composition and short-term changes due to specific rainfall or discharge events. The major phyla collected at the five stations are shown in **Table 3-6**.

The South Florida Water Management District (SFWMD) also conducted routine benthic macroinvertebrate sampling between February 1985 and March 1988. Samples were collected every other month at five sites in the Loxahatchee River.

Currently, SFWMD staff are reviewing the available macroinvetebrate data and intend to add several marine clams and snails as additional indicators of a healthy polyhaline ecotone in the Loxahatchee Estuary.

Table 3-6. Summary of Benthic Taxa Present in the Loxahatchee Estuary.

Station	Abundance (total mean)	Annelids	Crustaceans	Mollusks	Other	Total # of Species
B41	2812	54	36	64	4	73
B60	1599	39	41	15	5	85
B70	2795	61	22	11	6	113
B62	1913	17	48	13	22	76
B54	1605	44	42	4	10	66

Data from Dent et al. 1998.

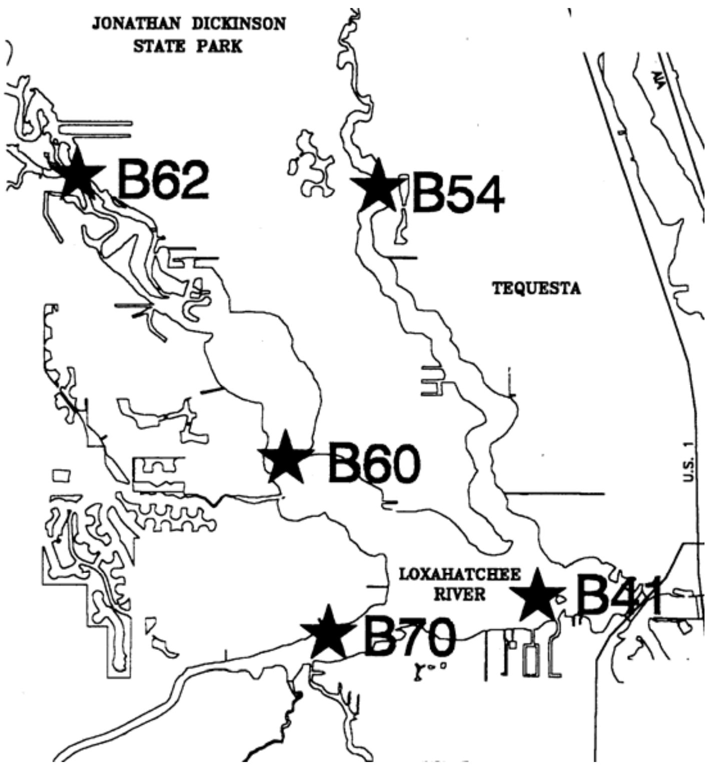

Figure 3-19. Location of Loxahatchee Estuary Macroinvertebrate Sampling Stations Used by Dent et al. 1998.

FISHES

Several studies have examined fish communities within the Loxahatchee River, including Christensen (1965), Synder (1984) and Hedgepeth (2001). Salinity studies have been conducted by Birnhak (1974), Rodis (1973), Chiu (1975) and Russell and McPherson (1984). The Loxahatchee River Environmental Control District has ongoing studies of fishes and salinity as well as invertebrates and seagrasses. Studies of fishes indicate that a significant relationship exists between community composition and salinity in the Loxahatchee River. The upstream area of the river (above RM 9.0) is characterized by freshwater species; the lower portion (from the Jupiter Inlet to RM 5.0) is characterized by marine and estuarine species; and the remaining midstream section (between RM 5.0 and RM 9.0) is characterized by freshwater and estuarine species.

Data from a study of fishes collected from the Loxahatchee Estuary during 1982-1983 (Hedgepeth, personal communication; Hedgepeth et al. 2001) indicate that the season of the year, salinity and availability of habitat have an affect on abundance, distribution and diversity of fishes in the estuary. The dominant fishes in the Loxahatchee Estuary are listed in **Table 3-7**.

Table 3-7. Relative Abundance and Ranking of the Most Abundant Fishes in the Loxahatchee Estuary During 1982–1983 (Hedgepeth et al. 2001).

Species	Specimens Rank	Biomass Rank	Appearance Rank	Sum of Ranks	Overall Rank
Dasyatis americana	16	15	16	47	19.3
Harengula humeralis	8	14	16	38	12.5
Harengula jaguana	2	3	16	21	7
Jenkinsia lamprotaenia	15	16	16	47	19.3
Sardinella aurita	9	12	16	37	11
Anchoa hepsetus	**1**	**2**	**13**	**16**	**3**
Anchoa lyolepis	6	16	16	38	12.5
Anchoa michilli	**3**	**8**	**7**	**18**	**5**
Synodus foetens	16	16	15	47	19.3
Strongylura notata	16	9	6	31	10.5
Strongylura timucu	16	16	11	43	15
Trachinotus falcatus	16	16	12	44	16
Diapterus auratus	16	13	9.5	38.5	13
Eucinostomus argenteus	**4**	**4**	**1**	**9**	**1**
Eucinostomus gula	**10**	**5**	**2**	**17**	**4**
Eucinostomus jonesi	13	16	16	45	17
Gerres cinereus	14	16	16	46	18.5
Archosargus probatocephalus	16	16	14	46	18.5
Lagodon rhomboides	12	10	5	27	9
Leiostomus xanthurus	**5**	**1**	**9.5**	**15.5**	**2**
Mugil cephalus	7	7	8	22	8
Mugil curema	11	6	3	20	6
Sphyraena barracuda	16	11	4	31	10.5
Spheroides testudineus	16	16	10	42	14

Bold text indicates the most abundant species.

The numbers of anchovies (*Anchoa* spp.) and herrings (*Harengula* spp.) peaked during the month of February, while the numbers of sciaenids (*Leiostomus xanthurus*), anchovies, herrings and mojarras (*Eucinostomus* spp.) peaked in July. These peaks reflected spawning periods for these groups. The seagrass beds of the Central Embayment, the lower North Fork and the lower Southwest Fork tend to support the highest number of species and individuals (**Table 3-8**). Abundance and diversity also were higher at sites where average salinities were above 25 ppt. At sites where salinities averaged 5 ppt or lower, the number of species decreased markedly. The most abundant species were anchovies (*Anchoa* spp.), mojarras (*Eucinostomus* spp.) and spot (*Leiostomus xanthurus*).

Table 3-8. Numbers of Fish Collected in Loxahatchee Estuary as a Function of Salinity (1982–1983).

Station Location	# of Individuals	# of Species	Salinity (ppt)		
			Mean	Minimum	Maximum
Central Embayment Area	185,936	102	24.6	3.0	35.0
Lower North Fork	20,405	62	21.3	6.0	35.0
Upper North Fork	945	30	3.7	0.0	22.0
Mid-Northwest Fork	911	30	4.6	0.0	19.0
Upper Northwest Fork	869	40	0.4	0.0	4.0
Lower Southwest Fork	49,416	68	9.8	0.0	27.0
Total for all Stations	258,482	144	15.6	0.0	35.0

Source: Hedgepeth et al. 2001

THREATENED OR SPECIES OF SPECIAL CONCERN

Manatees (*Trichechus manatus*)

The Florida manatee (West Indian manatee) is an important marine mammal that lives in or seasonally visits the Loxahatchee River system (Packard 1981). Manatees are federally protected by the Marine Mammal Protection Act of 1972 and the Endangered Species Act of 1973. They are also protected by the Florida Manatee Sanctuary Act of 1978, which establishes the entire state as a refuge and sanctuary for manatees.

The Loxahatchee River (Northwest and Southwest Forks) is considered a high priority water body because this area has a well documented history of manatee use. Manatees are found primarily in the Southwest Fork near S-46, the lower North Fork, Jupiter Inlet (river mouth) and residential canals. Nearby Jupiter Sound also has been identified as a seasonally important manatee feeding ground. The largest concentrations of manatees occur in October, January, and December (Law 1991b). Manatees and their calves have been observed apparently drinking fresh water at the S-46 Structure. This area also may be an important nursery area and mating behavior has been observed in this vicinity (Law 1991b). Although manatees can often be seen skimming fresh water off the surface and congregating at spillways and other freshwater sites, ingestion of fresh water in this manner is not a requirement (USFWS 1996). In general, manatees avoid areas with high boat traffic and tend to migrate upstream into Jonathan Dickinson State Park during rough weather. Concerns have been raised that hydrologic alteration of freshwater flows delivered to the estuary could potentially contribute to changes in the distribution or abundance of submerged aquatic plant communities, a reduction in water quality and/or a reduction in adequate levels of warm water that manatees require.

Opossum Pipefish (*Microphis brachyurus lineatus*)

The opossum pipefish was added to the candidate species list in 1997 (USDC 1998). The predominant areas in which there is concern for this pipefish is in the Indian River Lagoon of Florida. NMFS initiated a status review of this species in 1998 to determine if listing under the ESA is warranted.

The opossum pipefish is a circumtropical species; breeding adults are only found in freshwater associated with certain vegetation such as panic grass (*Panicum* spp.) and smartweed (*Polygonum* spp.). Brooding male opossum pipefish have been captured in tributaries to the

Indian River Lagoon, Florida, during all months except January and February. Predictable breeding adult populations are limited to tributaries of the Indian River Lagoon, the Sebastian, St. Lucie, and Loxahatchee rivers, thus the adult populations are restricted to the east coast of Florida adjacent to the warm Florida Current. These areas receive freshwater from inland and upland sources as part of an extensive coastal flood control system.

The main reason that the opossum pipefish is becoming very rare is that its habitat is disappearing as a result of several factors. First, continuous human settlement limits the areas in which these pipefish live. The rapid and continual growth of the coastal human population displaces pipefish habitat. Because these pipefish need access to very specific vegetation types and to freshwater, there are few places they can migrate. Furthermore, migration is limited because of flood control structures which block rivers and canals that could provide pipefish habitat. Lastly, herbicide treatment, which also destroys vegetated pipefish habitat, provides a potential threat for this limited Florida population.

Johnson's Seagrass (*Halophila johnsonii*)

Johnson's seagrass was listed as a federally endangered species in September 1998 (USDC 2000). It has a very limited distribution and it is one of the least abundant seagrasses within its range. It plays a major role in the viability of benthic resources and has been documented as a food source for the endangered manatees. The species is only known to reproduce asexually and may be limited in distribution because of this characteristic.

Johnson's seagrass has a disjunct and patchy distribution along the east coast of Florida from central Biscayne Bay to Sebastian Inlet. The largest patches have been documented inside Lake Worth Inlet. The southernmost distribution is reported to be in the vicinity of Virginia Key in Biscayne Bay. The species has been found in coarse sand and muddy substrates and in areas of turbid waters and high tidal currents.

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Valued Ecosystem Components (VECs) and Performance Measures (PMs)

The SFWMD supports the application of a resource-based management strategy similar to the Valued Ecosystem Component (VEC) approach developed by the U.S. Environmental Protection Agency (USEPA 1987). VECs are species or communities that relay a complex message of ecological community composition and health in a simplified and useful manner (USEPA 2000). Management objectives are attained by providing a suitable hydrological and water quality environment for the VECs. In turn, VECs sustain an important ecological or water resource function by providing food, living space, refugia and foraging sites for other desirable species in the ecosystem. This approach assumes that environmental conditions suitable for VECs also will be suitable for other desirable species and that the enhancement of VECs will lead to enhancement of other species.

Formulation of the Northwest Fork of Loxahatchee River ecosystem restoration plan is based on the VEC approach. The objective of this chapter is to identity VECs for each of the ecological reaches in the Northwest Fork, which are the freshwater floodplain, tidal floodplain and estuarine. Performance Measures (PMs) representing characteristic regimes of hydrology or salinity in the ecosystems are also identified for each of the VECs to evaluate restoration alternatives. These PMs are measurable and can be quantitatively or qualitatively related to the health of VECs.

THE FLOODPLAIN ECOSYSTEM

In this section the proposed Valued Ecosystem Components (VECs) and performance measures (PMs) for the riverine and tidal floodplain ecosystems are discussed. Rather than identifying individual species as VECs for the floodplain ecosystems, forest community types were used. Abundance and frequency of the primary canopy tree species within a forest community type were used to identify appropriate community-based VECs for the floodplain ecosystems. Three distinct reaches (riverine, upper tidal and lower tidal) and four major forest community types (swamp, bottomland hardwood, hydric hammock and upland) were identified on the floodplains of the Northwest Fork of the Loxahatchee River. The dominant canopy species listed in **Table 4-1** best reflect the native plant species that should be present for each forest community type. Appropriate water levels and hydroperiods for the community-based VECs provide performance measures for evaluating restoration alternatives.

Table 4-1. Summary of Hydrological Conditions, Soil Textures, and Dominant Canopy Species for the Floodplain Forest Communities in the Loxahatchee River and Its Major Tributaries.

Forest Type	Typical Hydrological Conditions	Primary Soil Texture	Dominant Canopy Species
Oak/pine	Flooded an average of once every 10 years; soils dry quickly after floods recede	Sand	*Pinus elliottii* *Quercus myrtifolia*
Hydric Hammock	Flooded average of 2 months (30-60 days) every year	Sand	*Sabal palmetto*
Mesic Hammock	Rarely inundated; soils elevated and dry quickly after floods recede	Sand	*Quercus virginiana*
Rblh3 Rblh2	Flooded an average of once every 3 years, sometimes for durations of 1-2 months or more; soils dry quickly after floods recede	Sand	*Quercus laurifolia* *Chrysobalanus icaco* *Ilex cassine* *Carya aquatica* *Persea borbonia*
Rblh1	Flooded average of 1 month every year; soils remain saturated another month	Sand, loam, clay	*Acer rubrum* *Cephalanthus occidentalis* *Persea palustris* *Salix caroliniona*
Rsw1 Rsw2	Flooded average 4-7 months every year; soils remain saturated another 5 months	Clay, muck	*Taxodium distichum* *Fraxinus caroliniana*
Rmix	Flooded 2 to 3 months every year	Sand	*Taxodium distichum* *Sabal palmetto*
UTmix	Flooded 2 to 3 months every year; soils dry quickly in some areas and remain continuously saturated in others	Loam, muck, sand	*Laguncularia racemosa* *Annona glabra* *Acer rubrum* *Salix caroliniana* *Cephalanthus occidentalis* *Taxodium distichum*
UTsw3	Flooded monthly by high tides or high river flows	Muck	*Fraxinus caroliniana* *Rhizophora mangle* *Laguncularia racemosa* *Annona glabra*
UTsw2 UTsw1	Flooded daily by high tides from 9-11 months of the year; most soils continuously saturated		
Hydric Hammock	Flooded every 1-2 years by either storm surge or high river flows, high water table, surface soils on higher elevations dry quickly and soils continuously saturated in lower areas	Muck, sand	*Sabal palmetto* *Chrysobalnus icaco* *Persea borbonia* *Quercus virginiana* *Myrica cerifera*
LTmix	Flooded daily or several times a month by high tides except in isolated areas; soils continuously saturated except for the interior of hammocks	Muck	*Lagunularia racemosa* *Sabal palmetto* *Rhizophora mangle* *Annona glabra*
LTsw2	Flooded daily for 9 months every year	Muck	*Laguncularia racemosa* *Rhizophora mangle* *Annona glabra*
LTsw1	Flooded daily every year	Muck	*Rhizophora mangle* *Laguncularia racemosa*

Data obtained from USGS 2002.

Green-shaded rows indicate riverine floodplain forest communities; yellow-shaded rows indicate upper tidal floodplain forest communities; and tan-shaded rows indicate lower tidal floodplain forest communities.

RIVERINE FLOODPLAIN VEC: SWAMP AND HYDRIC HAMMOCK FOREST COMMUNITIES

Justification

Cypress swamps and hydric hammocks are unique wetland forest types that are native and predominant in the riverine floodplain. Riverine swamp communities along the Northwest Fork of the Loxahatchee are dominated by bald cypress. In impacted areas, pop ash is abundant but in the long run will not out-compete longer lived bald cypress. Hydric hammock communities are dominated by cabbage palm with some live oak, wax myrtle, and red bay (**Table 4-1**). Swamp and hydric hammock forest communities are the selected VECs for the riverine floodplain. These community types are largely shaped by hydroperiod and water level. If appropriate hydroperiods and water levels are established for the target vegetation, then conditions should also be appropriate for healthy faunal communities.

In the dry season, hydroperiod and water level in the swamp communities should be geared toward keeping root systems moist and providing for germination of deciduous trees. In the wet season, hydroperiods and water levels in the hydric hammock communities should be sufficient to provide water and nutrients to that community and the needed inundation of swamp and bottomland hardwood ecosystems. This also provides increased habitat for aquatic organisms in the floodplain.

Distribution

Bald cypress swamps are typically found in the low floor of the floodplain immediately adjacent to the river. Hydric hammocks are generally found on higher elevations (about 1.5–3 feet higher than swamps) and do not receive regular tidal inundation or frequent river flooding. **Chapters 3** and **5** provide detailed descriptions of the distribution of these communities in each of the vegetation transects in the riverine floodplain.

Performance Measures

Wetland hydroperiods and water levels in the riverine floodplain, which are closely related to flows over the Lainhart Dam, are used as PMs for the riverine floodplain. **Table 4-2** provides a summary of suggested or observed hydroperiods and water levels for major wetland plant community types reported in the literature.

Table 4-2. Hydroperiods of Major Plant Community Types.

Plant Community Type	Wet Season Water Depth (inches below ground level)	Hydroperiod (days/year)
Mesic Flatwood	0-2	≤30
Scrubby Flatwood	Below ground	0
Dry Prairie	0-2	0-30
Sandhill	Below ground	0
Scrub	Below ground	0
Mesic Hammock	0-2	0-60
Wet Flatwood	2-6	30-60
Hydric Hammock	2-6	30-60
Depression Marsh	12-24	180-300
Slough	>36	230-360
Wet Prairie	6-16	60-180
Strand Swamp	18-36	210-300
Dome Swamp	12-24	210-300
Mangroves	___	Daily tidal
Maritime Hammock	___	10-45

Sources: Drew and Schomer (1984); Duever, Meeder and Duever (1984); Vince et al. (1989); Abrahamson and Hartnett (1990); Myers (1990); Mitsch and Gosselink (1993); David (1996); FDEP (2003a)

Based on literature values, swamp communities require about 210-300 days (7-10 months) of inundation per year and hydric hammock communities require about 30-60 days (1-2 months) of inundation per year (**Table 4-2**). However, the Northwest Fork of the Loxahatchee River is characterized by short periods of flooding followed by extensive periods of low flow. Hydroperiods for the floodplain swamps under such an environment should be shorter than what is shown in **Table 4-2**.

Based on available data and observations of the riverine floodplain ecosystem, it appears that wet season water levels in the Northwest Fork will allow for brief inundation of hydric hammocks in the range from 2 inches to 6 inches above the ground surface elevation. These inundations do not have to be continuous. The total number of days of such inundations during a year can range from less than 30 days to about 60 days, depending on elevation of the community and the hydrologic condition. The water levels in the floodplain will also provide a hydroperiod of 4 to 8 months inundation in a year to support a healthy swamp community in the riverine floodplain. During the dry season, the water level will range from about 0 to 1.5 feet below the ground elevation in the freshwater floodplain.

These proposed hydroperiods and water levels for swamp and hydric hammock areas are supported by other studies in rivers similar to the Northwest Fork. Light et al. (2002) have suggested 4-7 months per year for riverine freshwater floodplain. Darst et al. (2003) indicates that hydric hammocks in a riverine floodplain do not receive regular tidal inundation or frequent river flooding, but have a high water table and are briefly inundated by severe storms several times a decade. More detailed analysis of flow over the Lainhart Dam and floodplain inundation in the riverine floodplain are presented in **Chapter 5**.

TIDAL FLOODPLAIN VECS: SWAMP COMMUNITIES

Justification

Floodplain vegetation along the tidal reaches of the Northwest Fork of the Loxahatchee River has changed during the last 100 years from a freshwater bald cypress dominated floodplain to a mixture of fresh and saltwater species. The upper tidal reach is now characterized by freshwater riverine communities at higher elevations (dominated by bald cypress) and mixed swamps at lower elevations (fresh and saltwater species dominated by pond apple). At the higher elevations away from the river channel, freshwater plant communities are able to survive and reproduce due to groundwater flow from the uplands, rainfall, and increased distance from the river channel. Greater tidal amplitude and higher salinities have resulted in the dominance of red and white mangrove swamp in the lower tidal reach.

The restoration and enhancement goals for the upper tidal reach are to promote the increase in abundance and distribution of freshwater forest species in the canopy, shrub and groundcover components of the floodplain community and reduce the spread of mangroves and exotic plant species. As these freshwater species slowly return to the canopy, mangroves would become restricted to the shrub layer as currently is exhibited in the floodplains of lower Kitching Creek. Restoration and enhancement goals for the lower tidal reach will focus on reducing salt concentrations and increasing freshwater inundation to promote healthier sustainable habitats within the swamp and hydric hammock areas. Accordingly, freshwater swamp communities (**Table 4-1**) are the VECs for the tidal floodplain. Hydroperiod, tidal amplitude, and salinity are the criteria that will be examined for the tidal floodplain swamp VEC.

In addition to vegetative changes due to future reductions in salinity, improvements in the quality of the tidal soils are expected with regard to sulfide levels. Sulfide levels along Transect #9 (RM 6.46 - lower tidal), ranged from 2-179 µg/L during the wet season and <1-3007 µg/L during the dry season (USGS 2005). Areas in Transects #6 (RM 8.43) and #7 (RM 9.10 - upper tidal) also exhibited higher sulfide levels than in the less impacted riverine reach. These high sulfide areas can be easily identified because they are very difficult to walk through and generally will not support a person's weight. As fresh water and salt water mix in the tidal reaches, organic material is broken down forming hydrogen sulfide (H_2S) with its characteristic rotten egg odor and the organic sediment remains suspended in the water column. By moving the saltwater mixing area farther downstream, sediment particles in the upper tidal reach should coalesce and settle to the bottom, creating a more solid muck with reduced H_2S production.

Distribution

Upper tidal floodplain communities are dominated by mixed swamps and hydric hammocks (**Table 4-1**). Bald cypress and pond apple seedlings and saplings are present in the shrub and ground cover vegetation of the upper tidal reach. In the lower tidal floodplain communities, the canopy is comprised of mostly red or white mangroves depending on elevation. There is no evidence of freshwater seedling/sapling production in the lower tidal areas with the exception of pond apple, which appears to be salt tolerant.

Of particular concern in the tidal reaches is the distribution of white mangrove. This species appears to overlap the preferred elevations of pond apple communities. Most white mangroves are single trunk trees with limited branches while most pond apples are multi-trunk trees. These differences in growth habits appear to be directed at maximizing light availability for white mangrove and maximizing root structure for pond apple. On several transects, white mangroves appear to be shading out the older pond apple communities, although the stunted growth of pond apples may also be due to increases in the salinity of water and soil.

The 2003 Vegetative Transect Study provides a baseline evaluation of the target canopy, shrub, and groundcover species present in the upper and lower tidal reaches of the Northwest Fork of the Loxahatchee River. **Figures 4-1, 4-2** and **4-3** provide a summary of the abundance of target canopy, shrub and groundcover species as they occur across the three transects from uplands to the riverbed. Note that bald cypress only appears in the canopy of Transects #6 (RM 8.43) and #7 (RM 9.10) whereas pop ash appears in both the canopy and shrub layers of Transects #6 and #7. Pond apple appears in all three vegetative layers of all three tidal transects. Red and white mangroves are present in all three tidal transects. Mangroves can survive in freshwater environments (Odum et al. 1982). Therefore, no decline in the number of mangroves would be expected if salinities were lowered and freshwater flows were increased across the floodplain.

Performance Measures

One of the major concerns regarding restoration in the tidal floodplains of the Northwest Fork of the Loxahatchee River is the effect of saltwater intrusion and tidal amplitude on seed production, germination and seedling/sapling/adult growth and survival of bald cypress, other freshwater deciduous trees, and shrub and groundcover species. The performance measure for the tidal floodplain is a characteristic salinity regime in the Northwest Fork that is closely associated with the recruitment and health of these swamp species in the floodplain. The characteristic salinity regime and the justification for the bald cypress salinity threshold used for the evaluation are provided in the next sections.

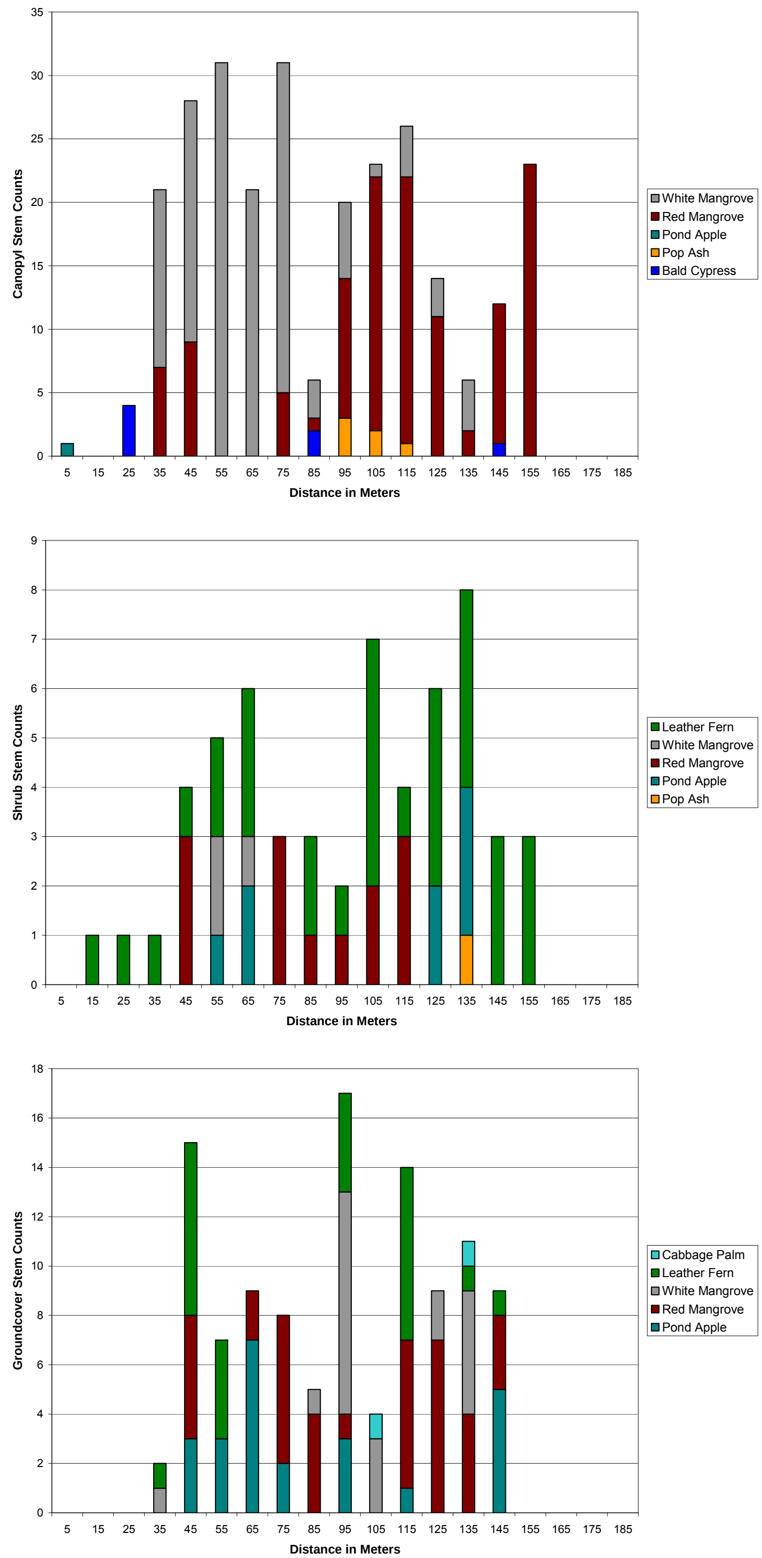

Figure 4-1. Select Canopy, Shrub, and Groundcover Species by Distance (in m) from the Uplands for Transect #6 (RM 8.43): Upper Tidal Reach.

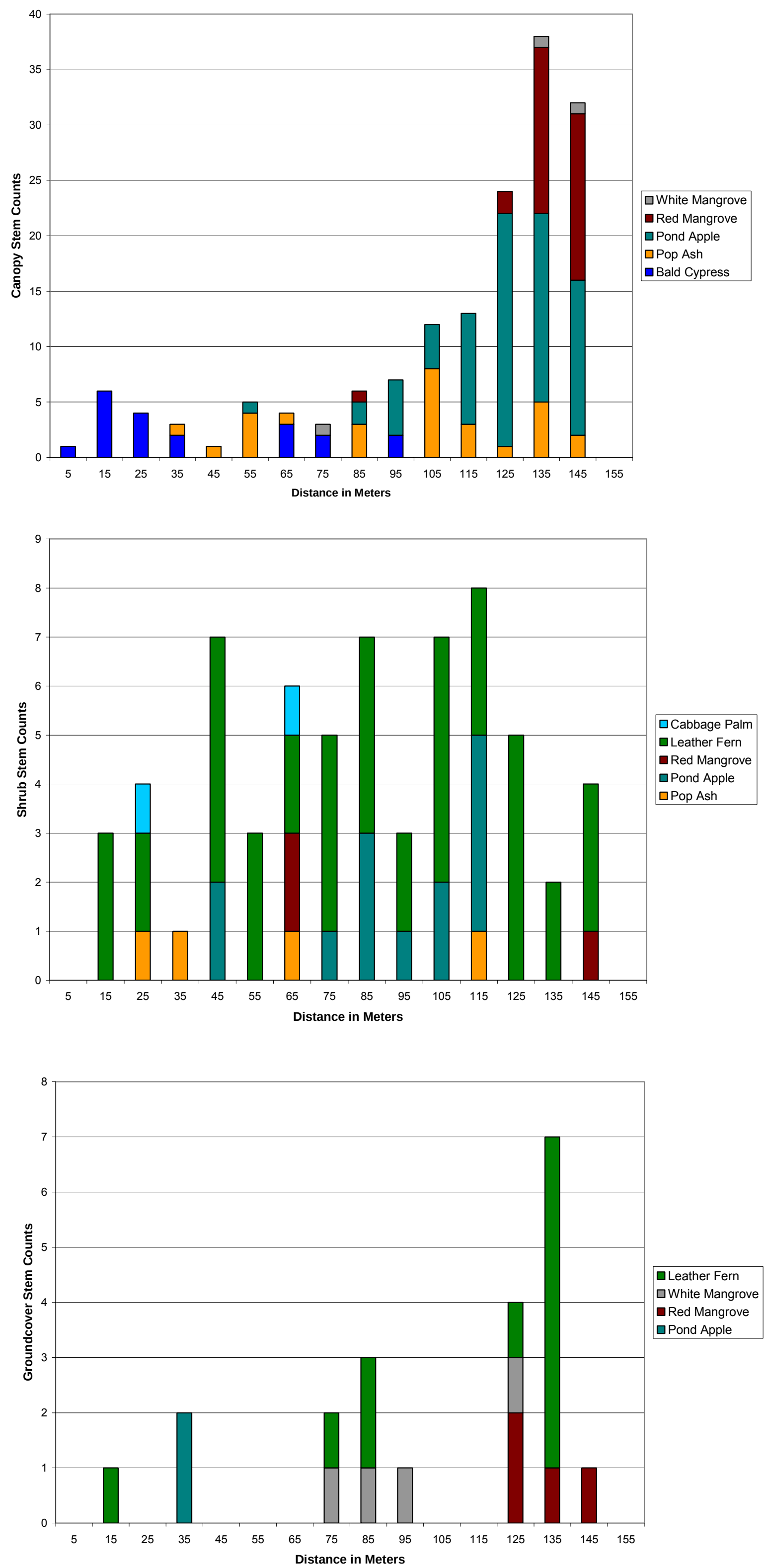

Figure 4-2. Select Canopy, Shrub, and Groundcover Species by Distance (in m) from the Uplands for Transect #7 (RM 9.10): Upper Tidal Reach.

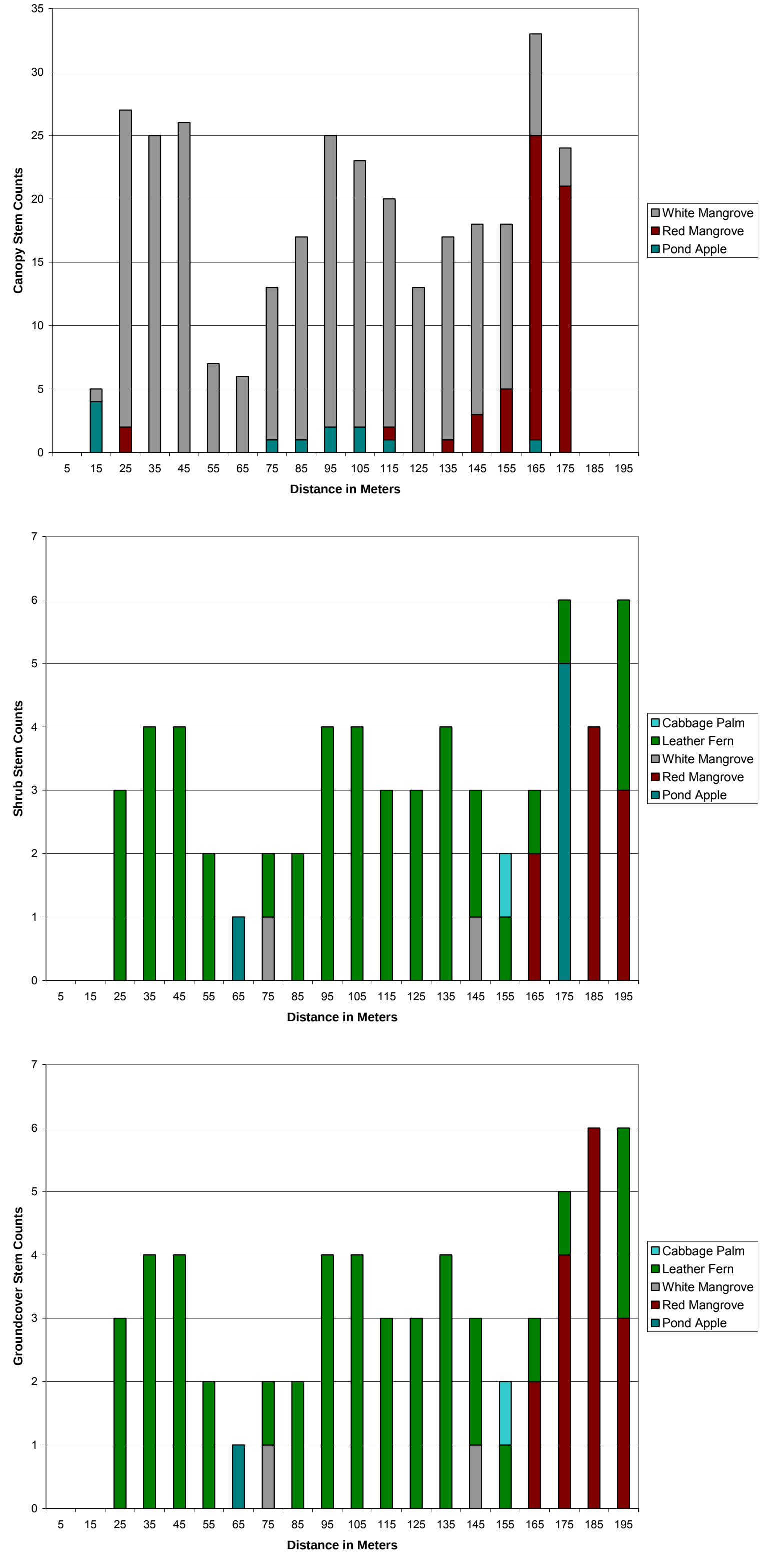

Figure 4-3. Select Canopy, Shrub, and Groundcover Species by Distance (in m) from the Uplands for Transect #9 (RM 6.46): Lower Tidal Reach.

CHARACTERISTIC SALINITY REGIMEN

The characteristic salinity regimen at a site in the Northwest Fork is defined by a ratio of the duration of all salinity events (*Ds*) to the duration between these salinity events (*Db*) over a long period of time such as over 30 years. The *Ds/Db* ratio integrates salinity exposure duration, magnitude and recovery time between salinity events into a single numerical factor. In **Chapter 6**, the long-term salinity data predicted by the salinity management model are presented. SFWMD staff concluded that the salinity regimen ratio *Ds/Db* (using 1 ppt threshold; see bald cypress salinity tolerance discussion section) showed a highly significant ($p < 0.0001$) negative correlation ($r^2 = 0.997$) with distance from the Jupiter Inlet (**Figure 4-4)**. As the site moves upstream, the *Ds/Db* ratio approaches zero since fewer salinity events occur. In contrast, the *Ds/Db* ratio exceeds one and rapidly increases as the site moves downstream, the magnitude and duration of each salinity event increases, and the time between salinity events decreases.

Use of the *Ds/Db* ratio affords a closer "fit" to salinity conditions than would have been provided by the use of standard descriptive statistics. SFWMD staff further found that the abundance and diversity of vegetation along the river corridor of the Northwest Fork is closely correlated to the salinity ratio, which provides a reasonable estimate of the status of the vegetation community at a site (Zahina 2004). **Chapters 8** and **9** demonstrate how increasing freshwater flows to the Northwest Fork during the dry season would change this salinity characteristic regimen, and ultimately change the tidal floodplain vegetation.

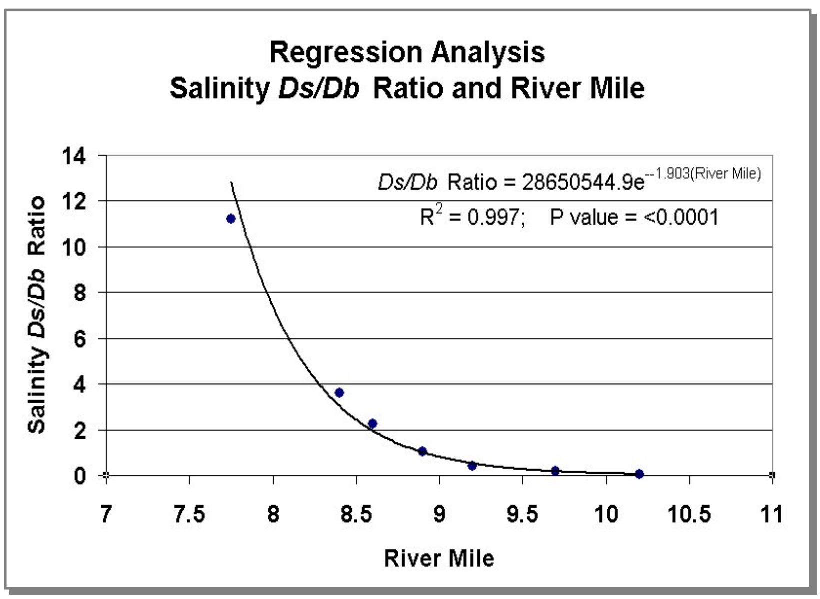

Figure 4-4. Correlation Between Salinity Event Ratio *Ds*/*Db* (> 1 ppt) and River Mile.

BALD CYPRESS SALINITY TOLERANCE AND THRESHOLD SALINITY

Bald cypress is the dominant canopy species in this floodplain swamp community; therefore, intra-seasonal biological and inter-seasonal hydrological needs to support seed production, germination and growth of bald cypress should be considered. From a reproductive standpoint, bald cypress is monoecious: both male and female strobili are produced on the same tree from buds formed during the previous year. Pollen from the male cones is generally shed in the spring and the seeds mature in the female cone scales between fall and early winter. Seeds are spread primarily by small animals and floodwaters. Germination takes place on the surface of the soil or moss. Seeds will not germinate under water but may remain viable for 30 months under water. A 1- to 3-month period of saturated soil conditions (but not flooded) is required for germination. Complete submergence of seedlings tends to hinder growth and prolonged submergence kills seedlings. Bald cypress can also reproduce vegetatively by producing sprouts (U.S. Department of Agriculture 1974).

In general, the literature suggests that bald cypress seedlings and adult trees are moderately salt tolerant. The growth of bald cypress seedlings is affected by a number of factors including soil type, soil moisture, nutrients present in flood waters, percent shading, crowding by competing vegetation, salt water, and duration and frequency of inundation. The combination of flooding and salinity is more detrimental to survival of bald cypress seedlings than the effect of either stress alone. Wicker et al. (1981) concluded that bald cypress wetlands are limited to areas where salinity does not exceed 2 ppt for more than 50% of the time that the trees are exposed to inundation or soil saturation. Allen et al. (1994) and Pezeshki et al. (1995) found that bald cypress seedlings exhibited intraspecific variation in tolerance to a combination of flooding and salinity stress. Allen et al. (1994) noted that 3 months of combined flood and salinity stress led to considerable decreases in leaf, stem and root biomass at 4 ppt and a notable decrease in root density index between the 4 ppt and 6 ppt treatments. Myers et al. (1995) found that 1- to 4-year-old seedlings planted in a frequently flooded marsh thrived despite a nearly constant groundwater salinity of 2.8 ppt. Conner and Askew (1992) observed that 6-month old seedlings were extremely susceptible to short-term (0-5 days) saltwater inundation (30 ppt) and survival percentages declined with more than one day of saltwater inundation. They also noted that at salinity levels above 4 ppt, the proportion of biomass partitioned to roots decreased. This was attributed to an ion imbalance causing severe disruption of root metabolic functions. Krauss et al. (1998) examined the effect of salinity levels on bald cypress germination. The germination percentages at salinity levels of 0 ppt, 2 ppt, 4 ppt and 6 ppt were 26.3%, 22.9%, 15.4% and 10.2%, respectively.

In conclusion, the available information in the literature does not suggest a single threshold salinity value for bald cypress. However, it is evident that as salinity levels approach 2 ppt and as the length of exposure increases bald cypress seed germination and seedling growth is reduced. Because of the tidal influence on salinity concentrations throughout a day, a conservative salinity threshold of 1 ppt is used to calculate the *Ds/Db* ratio in **Chapters 7** and **8.**

THE ESTUARINE ECOSYSTEM

Restoration scenarios being evaluated in this plan include increasing freshwater flows to the Northwest Fork of the Loxahatchee River. These additional flows may alter the salinity regime in the estuary, potentially impacting estuarine communities. Oysters and seagrasses have been selected as the VECs for evaluating potential changes in the mesohaline and polyhaline zones because, they

- are widely accepted as indicators of healthy estuarine systems;
- are currently present in the estuary;
- were present historically (post inlet construction) in the estuary;
- are sessile organisms that can not migrate away from unacceptable salinities; and,
- have fairly well-documented salinity ranges.

In addition, fish larvae in the low salinity zone are also proposed as a VEC for evaluation in the plan. These VECs and associated PMs are discussed in this section.

LOW SALINITY ZONE VEC: FISH LARVAE AND JUVENILE FISH

Justification

The Loxahatchee River and Estuary contain one of the more unique tropical peripheral ichthyofaunas within the United States. Jupiter Inlet lies only 7 km (4.6 mi) from the western edge of the Florida Current making the Loxahatchee River the only river on the east coast of the United States so close to a major tropical oceanic current. Thus, its biota is greatly influenced by adjacent tropical marine ecosystems, including those in the Antilles and Central America (Christensen 1965; Gilmore 1977, 1993, 1995; Gilmore et al. 1981; Snyder 1989; Swain et al. 1995). As a result, the most species rich estuarine communities within the continental United States are found in the Loxahatchee River and Indian River Lagoon (Swain et al. 1995).

Major recruitment of larvae into the Loxahatchee River occurs from riverine, estuarine or ocean spawning grounds during different estuarine flows and times of the year. Most temperate and warm temperate estuaries have major freshwater flows during the winter and spring (Peterson and VanderKooy 1995; Blaber 2000). Tropical systems differ significantly, however, since most flows occur during the summer and fall, typically peaking in the fall (Yanez-Arancibia 1985; Lowe-McConnell 1985; Blaber 2000). Many tropical estuarine and euryhaline freshwater species recruit during the winter and spring dry season when freshwater flow rates are minimal (Gilbert and Kelso 1971; Nordlie 1979, 1981; Gilmore 1993) which is the time period of interest for this evaluation. Since the Loxahatchee River Estuary contains a major tropical biota component it is likely that a high proportion of the biota have a life history strategy requiring tropical flow regime. A major, well-documented zooplankton event that predictably occurs throughout the world tropics during the dry season is an invasion of coastal tributaries to the lower salinity zone (LSZ) by large numbers of fish and invertebrate larvae (Gilbert and Kelso 1971; Nordlie 1979, 1981).

Several factors appear to make the low salinity zone (LSZ) a viable nursery. The LSZ may provide optimal salinity and temperature conditions for growth and development of larvae and juveniles (Pearce and Gunter 1957; Gunter 1961; North and Houde 2001). Low salinity itself and/or the high turbidity often characteristic of this zone may provide a refuge from predation (Turner and Chadwick 1972; Chesney 1989) and the dissolved nutrients and detritus associated with freshwater input make the LSZ highly productive. Freshwater flows enhance detrital and phytoplankton/periphyton based food chains in the LSZ which benefits larval and juvenile fish (Holmes et al. 2000; North and Houde 2001; Turner and Chadwick 1972). The presence of an adequate food supply, favorable environmental conditions, and/or a refuge from predation ensures successful development and survival (North and Houde 2001). For example, in the stratified upper Chesapeake Bay, high flows may create a well-defined low salinity entrapment zone with an organic rich turbidity maximum that supports an abundance of zooplankton prey (North and Houde 2001). Fish larvae are retained in an optimal salinity environment that provides a rich food supply, and a refuge from predation through high turbidity (North and Houde 2001). During low flow, the entrapment zone is weaker and more diffuse. The turbidity maximum is less well defined and relatively depleted in organic matter. Production of zooplankton prey is limited and larvae may experience suboptimal salinities owing to reduced retention capacity (North and Houde 2001). In contrast, in the well-mixed estuary of the Parker River, a phytoplankton bloom in the oligohaline zone (0.5 ppt to 5.0 ppt) during low flow conditions supports a productive pelagic food chain. A long hydraulic residence time allows phytoplankton and zooplankton to accumulate in the upper estuarine LSZ. During higher flow conditions, the bloom and accompanying larvae are flushed down the estuary (Holmes et al. 2000). It is believed that the Loxahatchee Estuary experiences these same types of relationships that influence the survival of year class larvae and therefore need to be evaluated as various levels of dry season flows are considered.

Distribution

To determine the distribution and abundance of fish and shellfish larvae in the waterway of the LSZ, a sampling program was conducted in 2004. The 2004 study was undertaken during the dry season to determine the influence the LSZ in the Northwest Fork has on larvae recruitment and abundance as well as species composition (Shenker 1983; Houde 1994; Blaber 2000; Dege and Brown 2004). Four regions between River Miles 6 and 10 were chosen for the initial collections in this portion of the Northwest Fork (**Figure 4-5**). Each region centered on/around RM 7, RM 8, RM 9, and RM 10 with a single replicate tandem plankton tow within 20-50 m of the previous tow. This allowed eight paired stations: Stations 1 and 2 (RM 10), Stations 3 and 4 (RM 9), Stations 5 and 6 (RM 8) and Stations 7 and 8 (RM 7). During late June (25^{th}) and early July (6^{th}) Stations 1 and 2 had to be abandoned due to extremely low water levels.

Zooplankton collections were also conducted within the Loxahatchee River and Estuary from January 1986 to January 1988 by Robert Chamberlain of SFWMD. Two of the sample sites were located within the Northwest Fork of the Loxahatchee River at Station 25 (RM 5.8) and Station 28 (RM 7.0). This study allowed a qualitative and quantitative comparison to be made with 2004 zooplankton collections.

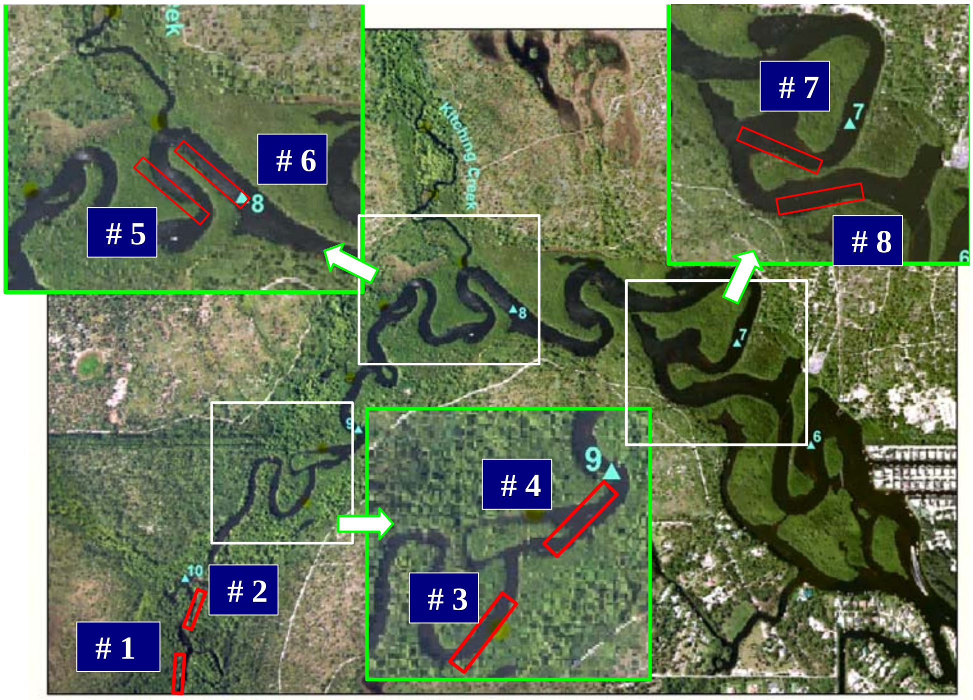

Figure 4-5. Location of 2004 Dry Season Fish Larvae Sample Stations Indicated by Red Rectangles. Station Numbers are Represented by White Numbers on a Blue Background; Light Blue Numbers Indicate River Mile.

During the 1986-1988 study (Chamberlain unpublished), fish families with the largest total number of larval individuals collected at Station 28 (RM 7) were the gobioids (64%), engraulids (anchovies, 28%) and syngnathids (pipefishes, 2%; **Figure 4-6**). During the 2004 dry season, the largest total number of larval individuals collected from all stations were the gobioids (87%), engraulids (11%) and syngnathids (1%; **Figure 4-7**)

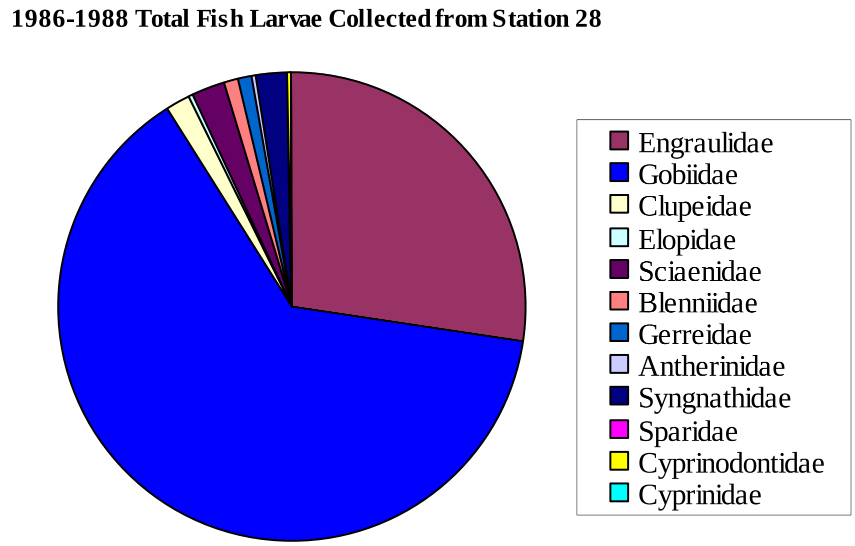

Figure 4-6. Relative Composition of All Fish Larvae by Family Collected in 1986-1988 at Station 28 (RM 7.0). Source: Chamberlain unpublished.

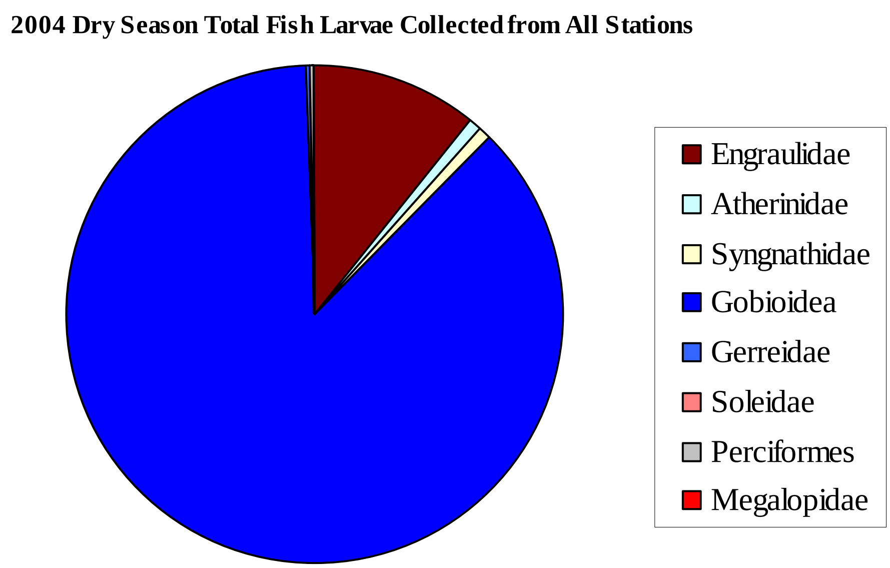

Figure 4-7. Relative Composition of All Fish Larvae by Family Collected During the 2004 Dry Season for All Stations.

Larval fish species composition varied seasonally at Station 28 (RM 7) in 1986 and 1987. There was a dominance of gobioid species at the end of the dry season followed by a dominance of engraulid species at the beginning of the wet season (**Figure 4-8**). The seasonal variation relative to fish larval abundance can be attributed to salinity and water level changes in the Northwest Fork.

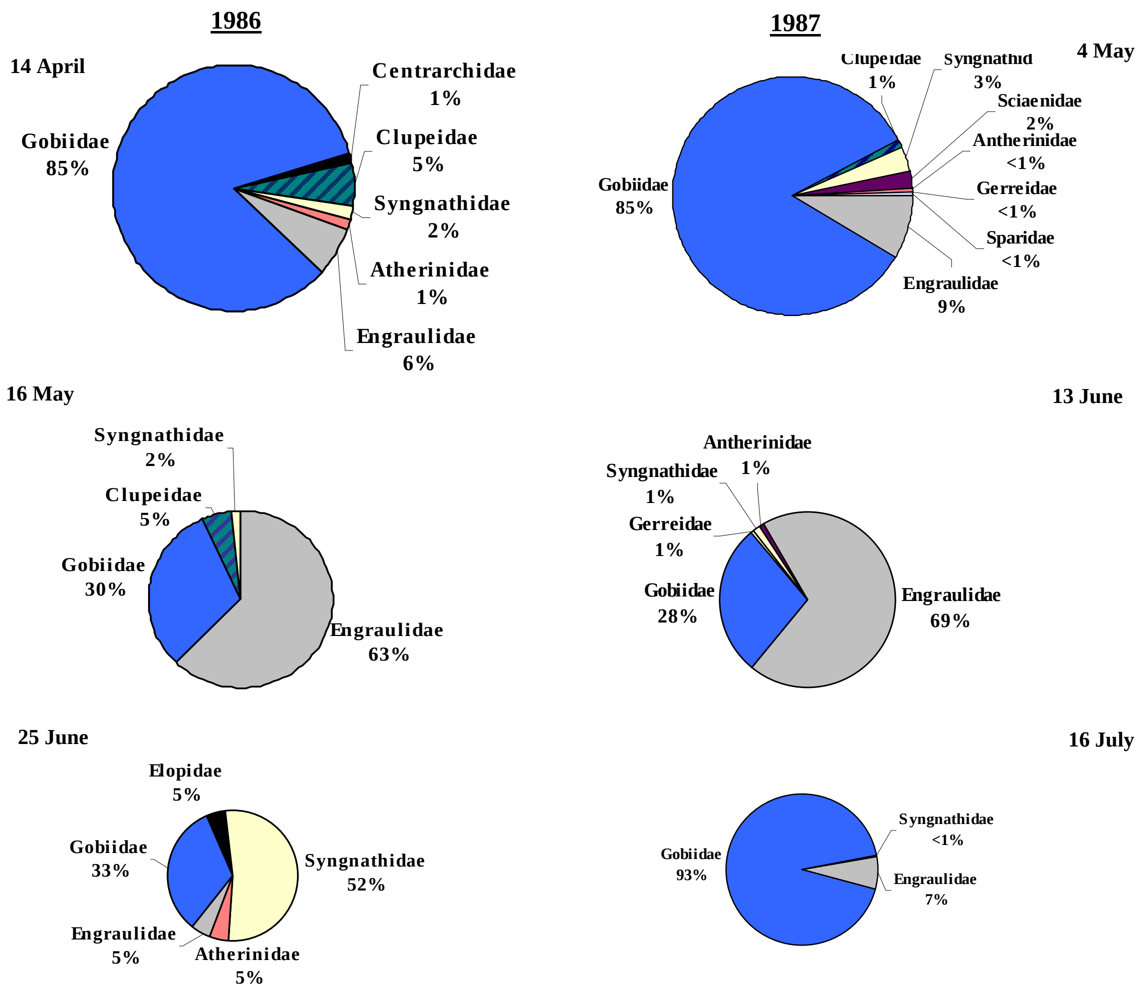

Figure 4-8. 1986 and 1987 Seasonal Changes in Relative Abundance of Fish Larvae During the Transition from the Spring (Dry Season) to the Summer (Wet Season) at Station 28 (RM 7.0).

Changing water levels and salinities appear to have the greatest influence on the density and species composition of fish larvae within the LSZ. The 1986-1988 data were used to compare the density of fish larvae collected from Station 28 (RM 7) with larvae collected downstream at Station 25 (RM 5.8). Higher densities of fish larvae were present at Station 28 than at Station 25 (**Figure 4-9**). Because the water level fluctuations at these two sites were similar, it appears that salinity has a greater influence on fish larvae distribution than water level.

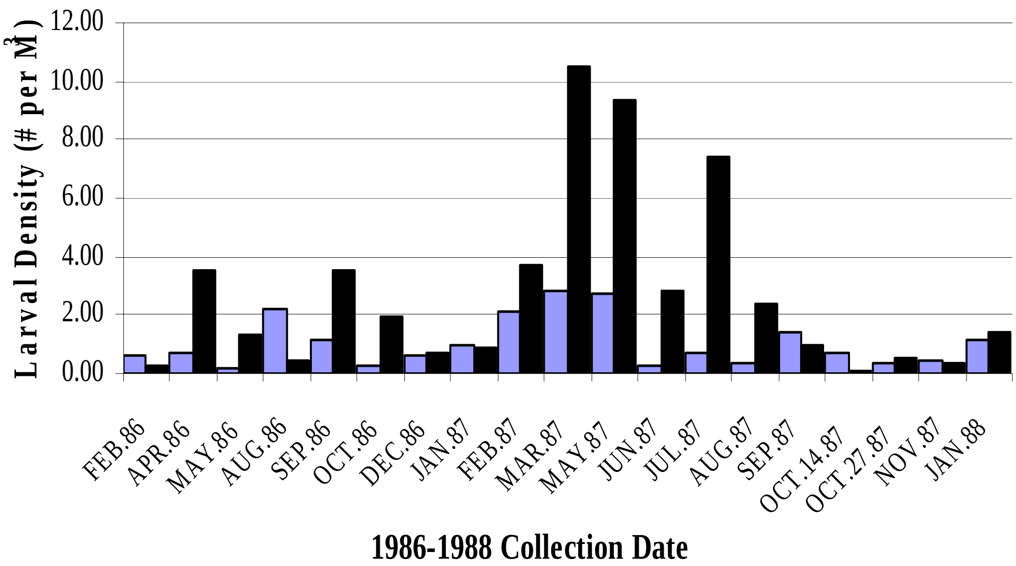

Figure 4-9. 1986-1988 Fish Larvae Densities from Station 25 (RM 5.8) (Blue Bars) and Station 28 (RM 7) (Black Bars).

The highest densities of fish larvae at Station 28 typically occurred during the dry season (February – April 1986; February – March 1987) when the salinities were between 2 ppt and 8 ppt (**Figure 4-10**). The lowest densities of fish larvae occurred during the wet season (December 1986; October – November 1987) when the salinities were below 2 ppt.

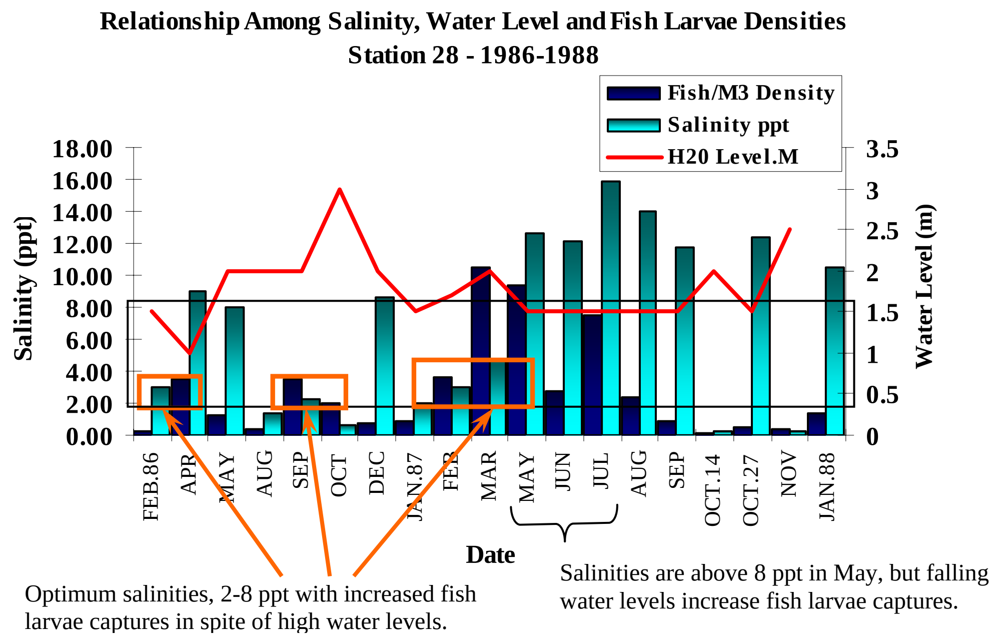

Figure 4-10. 1986-1989 Fish Larvae Densities at Station 28: Relationship between Salinity and Water Level.

The relationship between salinity and water level on fish densities during the 2004 dry season study (**Figure 4-11**) is similar to the 1986-1988 data. The highest fish larvae densities were found at the RM 9 and RM 8 locations where salinities were between 2 ppt and 8 ppt. A more detailed discussion of the 1986-1988 and the 2004 sampling programs is provided in **Appendix H**.

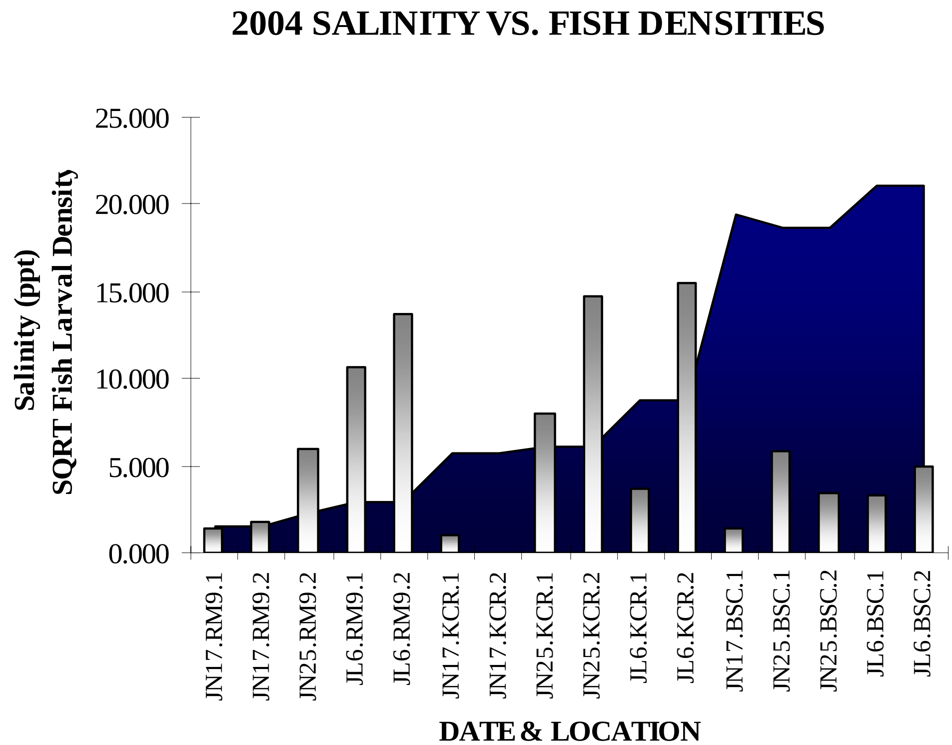

Figure 4-9. 2004 Dry Season Fish Larvae Density Relative to Salinity (ppt).

Performance Measures

The results from the 1986-1988 and 2004 dry season sampling programs indicate that the highest densities of fish larvae were found within the LSZ where salinity levels ranged from 2 ppt to 8 ppt. The dominant fish species present in the LSZ are gobies (gobioids), anchovies (engraulids) and pipefishes (syngnathids). During the dry season the density of silversides (antherinids) also increases. Because of the relatively small volume of water in the LSZ of the Northwest Fork of the Loxahatchee River, even small increases of flows to the Northwest Fork will increase the size of the LSZ area, affect the salinity and may influence the distribution and abundance of larval and juvenile life stages of fish. Based on the SFWMD investigations, a dry season salinity of 2 ppt to 8 ppt between RM 5.5 and RM 10.0 is suggested as the Performance Measure for larval and juvenile fishes in the LSZ. Detailed discussions of this conclusion are given below.

The optimum natural condition in which to examine the influence of freshwater flow on a riverine fauna is to examine the fauna at the lowest possible flow condition over a broad enough range of salinity within the shortest spatial and temporal (diel) range practical. We tested two null hypotheses: 1) “$H^o{}_1$ No particular taxon consistently numerically dominates the larval fish communities indigenous to the Loxahatchee River”; and 2) “$H^o{}_2$ Fish larval abundance is evenly distributed between RM 6 and RM 10 in the main course of the river during the “dry season” low rainfall, low flow periods, winter to late spring/early summer (December to July).”

“H^{o}_{1}″ *Loxahatchee River Larval Fish Community Defined*: Our results demonstrated that a diverse yet predictable larval fish community occurs within the Loxahatchee River and is consistently numerically dominated by three to four fish families. This fauna consists primarily of gobies (gobioids), anchovies (engraulids), pipefishes (syngnathids) and silversides (atherinids) during the dry season. These same taxa numerically dominated samples taken at Station 28 in 1986 to 1988 and in 2004 revealing a long term consistency in fish larval community structure within the Loxahatchee River.

The warm Florida Current along the lower east coast of the Florida produces a subtropical-tropical coastal oceanographic and climatic/hydrological setting for the Loxahatchee River (Christensen 1965; Gilmore 1977, 1985; Gilmore and Hastings 1983). There is a distinct wet season with natural high riverine flows and low salinity occurring during the summer and fall, followed by a dry season with low flows and high salinity starting in the late fall extending though the winter and spring (Gilmore 1977; Gilmore and Hastings 1983). These seasonal flow patterns influence fish spawning periodicity and larval recruitment as well as levels of primary and secondary productivity. The Jupiter Inlet, Hobe Sound and the Loxahatchee River region is largely dominated by tropical and warm temperate fish species (Christensen 1965; Gilmore 1977, 1995). Recent studies of the neighboring the St. Sebastian River documented a similar pattern of fish species (Paperno and Brodie 2004). These regions often contain large numbers of marine and estuarine diadromous species that enter the freshwater for extended periods of time to complete vital developmental or reproductive phases (McDowall 1988). The numerical dominance of tropical marine and estuarine species in freshwater habitats is typical of many coastal settings in the tropical Americas and Caribbean islands (Blaber 2000). In the Loxahatchee River, the marine fish families, gobioids, engraulids and synganthids are the top diadromous euryhaline spawners.

The dominance of gobioid larvae is typical of tropical estuaries throughout the world. Where gobies have adapted to temperate estuaries they numerically dominate the ichthyoplankton (Shenker et al. 1983). The gobioid fishes can also numerically dominate open ocean ichthyoplankton (Richards 1984; Ahlstrom 1971, 1972; Nellen 1973). This family represents the richest fish faunal element in the Loxahatchee River with at least 16 species occurring in this small coastal stream system. The anchovies, engraulidae, are next in abundance possibly including both tropical and temperate species. They are typically the most numerically abundant marine and coastal estuarine fish as adults. Other marine and estuarine species that were common or occurred in the 1986-1988 and in the 2004 samples were larval mojarras (gerreidae), drums and croaker (sciaenidae), herrings/sardines/menhaden (clupeidae), silversides (atherinidae) and pipefishes (syngnathidae). The 1986-1988 collections also included some larval blennies (blennidae), and various flatfishes (soleidae, bothidae and cynoglossidae). These fish families also are commonly represented in tropical freshwater tributaries elsewhere in the world (Blaber 2000).

Although five species of snook are found in the Loxahatchee River, the common snook, *Centropomus undecimalis*, largescale fat snook, *C parallelus*, smallscale fat snook, *C. mexicanus*, tarpon snook, *C. pectinatus* and the swordspine snook, *C. ensiferus*, no larval snook (centropomids) were collected in the 1986-1988 or 2004 samples. All five snook species have been captured as juveniles and adults in the Loxahatchee, St. Lucie and St. Sebastian Rivers. No other stream or river system in Florida has all of these species. Even though no centropomid larvae were present in the 1986-1988 and 2004 samples, snook eggs and larvae were abundant in a sample made within Jupiter Inlet on 2 July 2004 indicating that snook were spawning at that time.

Larvae of primary freshwater fishes, centrarchids, cyprinids, percids and catostomids, were also absent from in the 2004 samples. Centrarchids and cyprinids were listed as having been collected in the 1986-1988 samples at Station 28, but these groups did not form a large portion of the larval collections. The freshwater fish fauna of the southern Florida peninsula is numerically dominated by euryhaline secondary freshwater families, anguillidae, cyprinodonts, poeciliids and atherinids and many marine invaders particularly in coastal streams. Euryhaline marine/estuarine invaders are present either as juveniles and adults, but not necessarily as larvae. These include bull sharks, ladyfish, tarpon, ariid catfishes, and mullets, snooks, centropomidae, mangrove snapper, burro grunt, sheepshead porgy, sciaenids, cichlids and various flatfishes, bothids, cynoglossids and soleids. Soleid larvae were present in the 2004 samples. These families and the general invasion of freshwater by adults and juveniles of marine and estuarine phyla is a worldwide tropical phenomenon (Blaber 2000). Very few marine fishes in these families actually spawn in low salinity waters. Nearly all spawn in the ocean and their larvae require higher salinities to survive.

“$H^o{}_2$"*Fish Larval Dynamics Relative to Salinity and Water Depth*: The dynamics of the Loxahatchee river ichthyoplankton community was examined relative to collection sites, salinity, and water level using the 2004 and in the historical 1986-1988 collections. Additional parameters evaluated for the 2004 collections included temperature, dissolved oxygen and water flow rates but since these parameters did not vary significantly between stations during the recent ichthyoplankton survey it appears that salinity is the major factor responsible in influencing densities. However, the major portion of the ichthyofauna was captured at the confluence of the Kitching Creek and the main course of the Loxahatchee River. This could also be a site of nutrient flow, organic materials and consequently, primary productivity which would then produce a microzooplankton bloom of copepods and ostracods that were not captured with the net we used. This microzooplankton bloom would then feed larger invertebrate plankton and fish larvae. Nutrients and organic material concentrations were not examined so the influence of these parameters on fish larval distribution could not be determined. It is also possible that the large low tide captures on an ebbing tide, 25 June and 6 July 2004 could be due to the fact that even though the fish and invertebrate larvae typically migrate to the surface at night, they might not do so on an ebbing tide as they may be carried out into the adjacent estuary. In order to maintain an upstream position they would migrate to the river bottom. The 0.5-m plankton net may have sampled this bottom habitat in upstream waters between RM 8 and RM 9 while the water depth was too great to sample the bottom habitat at Stations 7 and 8 at RM 7. This would produce higher larval densities upstream simply as a sampling artifact. However, the high tide collection made on 17 June also captured more invertebrates between RM 8 and RM 9 than at RM 7, indicating the 2-8 ppt salinity region and its high ichthyoplankton density was likely not a sampling artifact.

The 1986-1988 collections were always made on a flood or high tide yet revealed the same fish larvae species ranking based on numerical abundance with most larvae captured when salinities were between 2 and 8 ppt for both Stations 28 and 25 (see **Chapter 7**, **Figure 7-11**) with the greatest abundance at Station 28 at RM 7. Where this salinity range (2 to 8 ppt) occurred, the greatest concentration of fish larvae also occurred in 2004 between RM 8 and RM 9, with most larvae being captured in the vicinity of the mouth of Kitching Creek at RM 8. The highest density of fish larvae captured in the Pautuxent River (Shenker et al. 1984) were captured between salinities of 2-3 ppt. Similar salinity association patterns were observed in the San Francisco Estuary (Dege and Brown 2004). Apparently, fish larvae concentrate in the Low Salinity Zone of estuarine systems; however, since each system has unique characteristics, field investigations need to document this important low salinity range for each estuary. Thus, the 2 ppt to 8 ppt range supporting the highest density of fish larvae, under low flow conditions in the Loxahatchee River, is unique to this estuary.

MESOHALINE ZONE VEC: OYSTERS

Justification

Estuaries are transitional environments in which salinity varies between freshwater and seawater (Moyle and Cech 1982) and the amounts of freshwater runoff and tidal flushing largely determine the biological character of an estuary (McPherson et al. 1984). One important biological component of the Florida estuaries is the distribution and health of the eastern oyster (*Crassostrea virginica*). This species of oyster thrives best in estuarine waters with a yearly average salinity between 10 ppt and 20 ppt (Woodward-Clyde 1998). Therefore, since adult oysters are sessile, estuarine locations that experience these favorable salinities may accommodate oyster health. Changes in freshwater runoff characteristics from the watershed could alter the salinity gradient in the estuary; thus the location of healthy oyster populations will reflect the 10 ppt to 20 ppt salinity levels.

Oyster reefs provide significant habitat structure and value within the benthic environment in the Loxahatchee Estuary; those areas of the estuary without oyster reefs have limited structure. Oyster reefs provide extensive attachment area for numerous organisms including oyster spat, mussels, tunicates, bryozoans, and barnacles (Woodward-Clyde 1998). Several studies have demonstrated the high species richness of oyster reefs (Pearse and Wharton 1938; Frey 1946; Wells 1961; Bahr and Lanier 1981).

Oysters play an important role in the estuarine food chain and filtering the water. Free-swimming oyster larvae are frequently preyed upon by planktivores, such as ctenophores, anemones, and larval fishes; and spat are eaten by carnivorous worms and small crabs (Woodward-Clyde 1998). Larger spat and small adult oysters are often consumed by blue crabs, stone crabs, whelks, skates, rays and fishes such as black drum and redfish (Wells 1961). Loosanoff (1946) indicated that oysters filter water at a rate of about 1500 times its body volume per hour. Maintaining a healthy, sustainable oyster population would help water quality and provide important habitat within the system. In order to maintain a healthy population of oysters in the middle Loxahatchee Estuary, the average annual salinity should be near 15 ppt; exposure to salinities below 10 ppt can be stressful to oysters. The specific salinity tolerances of oysters related to stress, harm, and death are presented as a Performance Measure.

Distribution

Early European settlers called the receiving water body of the Loxahatchee Watershed “Jupiter River” which was frequently a freshwater river that did not support oyster populations. Periodically, however, the Jupiter Barrier Island was breached as a result of storm events, creating passes that allowed seawater to intrude into the river and create an estuarine environment. During these times, the Central Embayment supported a large oyster population. These passes would naturally fill in, returning the river to a freshwater environment uninhabitable by oysters. In the late 1940s, the Jupiter Inlet and the Intracoastal Waterway, which connected the Loxahatchee River with the Indian River and Lake Worth Lagoons, were dredged and stabilized. This dramatic alteration enabled estuarine conditions to occur on a regular basis in the Loxahatchee River Estuary. Salinity conditions at that time favored the development of oyster reefs near the mouth of the estuary at the FECRR trestle. As these reefs developed through the years they reduced navigation, tidal communication and water quality within the estuary. Several studies in the mid-1970s were conducted to address the potential increase in saltwater intrusion and tidal currents into the Northwest Fork if the oyster reefs were removed from the trestle area

(Christensen 1973; Chiu 1975; Hill 1977). A mathematical salinity model predicted that with the removal of the oyster reefs, the slack high tide salinity would move 260 feet to 600 feet further upstream in the Northwest Fork; however, the oyster reefs were removed by 1978.

After the removal of the oyster reefs, the U.S. Geological Survey conducted field investigations in 1980-1981 that provided information on bathymetry, hydrology, and benthic sediment and biota. A map resulting from this effort revealed nine small, live oyster reefs in the Central Embayment (McPherson 1982) with a total area less than 1.5 acres. Another survey in 1985 mapped oysters in the Central Embayment and suggested a decrease in area of live oyster reefs from 1981 observations (Klemm and Vare 1985). No effort was made in either of these studies to determine the presence of adult oysters in the Northwest Fork of the Loxahatchee River. In 1990 there was an investigation of oyster distribution and size throughout the Loxahatchee River which included the Northwest Fork (Law Environmental, Inc. 1990). In 1990, the Central Embayment was regularly experiencing salinities greater than 25 ppt. The oyster reefs present were small and mostly dead due to decreases in food supplies and increases in predation and disease. Based on field observations (Law Environmental, Inc. 1990), the oysters were smallest at their upstream and downstream locations and largest (80–90 mm) in the central part of their range in the Northwest Fork, which extended from the trestle bridge to about RM 6.5. The largest living oysters occurred between RM 4.0 and RM 6.0 which indicated that this area experienced the most favorable conditions for oysters in 1990. In contrast, large dead oyster shells were found in the Central Embayment, remnants from the former lower salinity environment.

In October 2003, under a contract with the SFWMD, the LRD conducted an oyster survey in Loxahatchee River and Estuary (Wild Pine Ecological Laboratory 2004). The live oyster reefs surveyed were defined as areas having at least five live oysters per square meter. The area of concern for this document, however, is in the Northwest Fork as shown in **Figure 4-12**, where 9.6 acres of oysters were mapped between RM 4.0 to RM 6.0 (**Figure 4-13**). The density of live and recently perished oysters as well as their total length (grouped into three classes: < 5 cm, 5-10 cm, and > 10 cm) were collected at four locations in the Northwest Fork (**Figure 4-14**). The majority of the oysters (76%) were < 5 cm in length, 23% were between 5 and 10 cm long, and only 0.2% greater than 10 cm long. The highest density of oysters and largest area of reefs occurred at RM 4.5 (900 oysters/square meter). Density decreased upstream to about 690 oysters/square meter at RM 5.5 and to 410 oysters/square meter at RM 6.0.

Figure 4-10. 2003 Distribution of Oyster Reefs (yellow areas) in the Northwest Fork of Loxahatchee River. Oyster Monitoring Stations are Indicated with Red Dots (Source: Wild Pine Ecological Laboratory 2004).

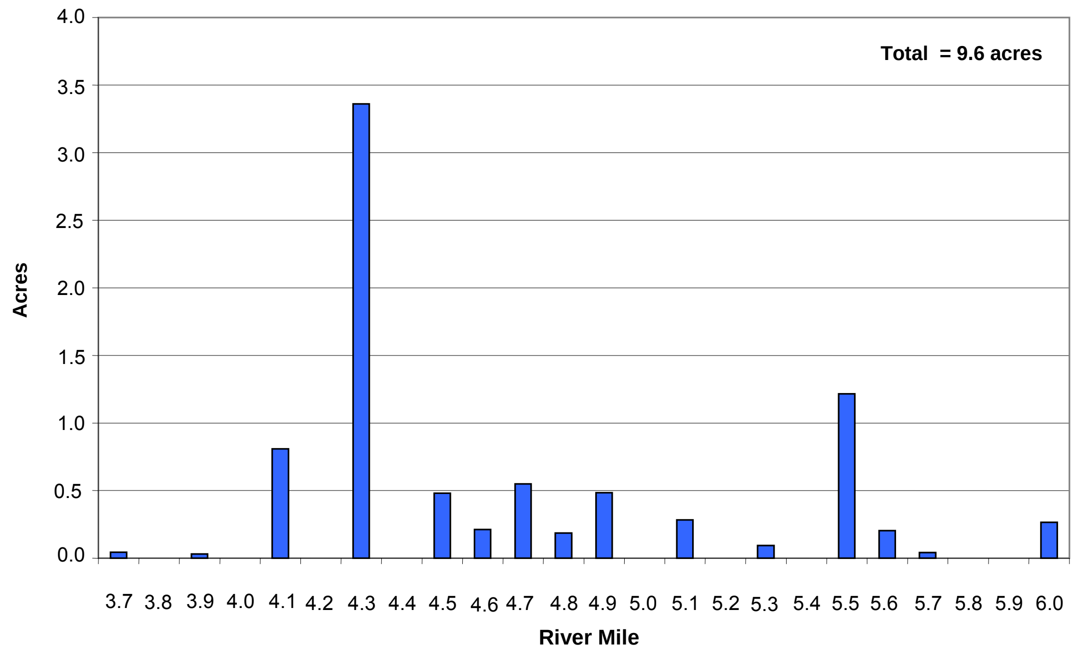

Figure 4-11. Oyster Acreage in the Northwest Fork of the Loxahatchee River Estuary in October 2003 (Source: Wild Pine Ecological Laboratory 2004).

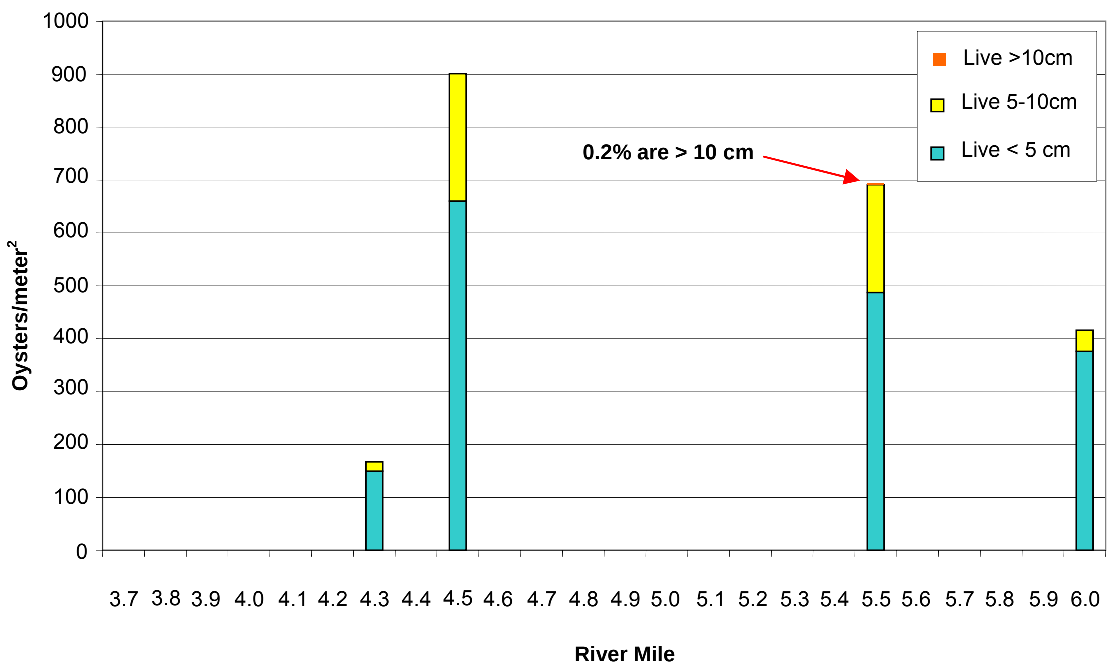

Figure 4-12. Oyster Distribution in the Northwest Fork of the Loxahatchee River Estuary in October 2003 (Source: Wild Pine Ecological Laboratory 2004).

Performance Measures

The salinity tolerance of oysters (*Crassostrea virginica*) between RM 4.1 and RM 5.9 is identified as a PM for the Plan. **Table 4-3** defines the stress level of the life history of oysters (eggs, larvae, spat, and adults) in relation to salinity and the duration of exposure. The evaluation methods used for the performance measures are described in **Chapter 7**.

Suitable habitat for the eastern oyster within an estuarine salinity gradient from freshwater to seawater is predominately influenced by salinity, food supply, availability of appropriate substrate (cultch), disease and predation. A combination of these factors results in sparse densities or absence of oysters in the upper and lower portions of the estuary, and high densities (near 1000 oysters/m^2) in the middle portion of the estuary. Low oyster densities in the upper estuary occur due to frequent exposure to harmful or lethal low salinities while low oyster densities in the lower estuary result from limited food supply, high predation and disease (*Perkinsus marinus*). The most suitable habitat with the highest densities of oysters is in the middle portion of the estuary where the salinity ranges from 10 ppt to 20 ppt. This salinity range is favorable for reproduction, growth, and food supply and the reduced presence of disease and predators is well documented at these salinities. The major focus of this evaluation for the Loxahatchee Estuary is on the region from the upper estuary, where oyster density is lowest (near RM 6.0), to the middle estuary (near RM 4.0) where oyster density is highest. Limiting the evaluation to this region minimizes the need to quantitatively describe the affects of predation and disease on oyster density in the lower estuary which is not included in this evaluation. Of all the factors influencing oyster density, salinity or salinity as a surrogate is used to explain a major portion of the effects freshwater flows have on the oyster population. In order to describe these effects, an understanding of salinity tolerances of oysters at each life stage is necessary.

Table 4-3 shows salinity values and exposure durations for four oyster life stages (eggs, larvae, spat, and adult) that cause oyster stress, harm, and mortality. Most of these salinity values and durations were obtained from the literature for oyster populations for areas other than Florida, however, recent reports on salinity affects on juvenile and adult oysters from the Caloosahatchee and St. Lucie estuaries, Florida (Volety et al. 2003; Roesijadi 2004) were also included. A recent study of oyster life history in the St. Lucie Estuary, immediately north of the Loxahatchee Estuary (Wilson et al. 2004), was used to time oyster life stages in the Loxahatchee Estuary. A major spawn occurred in the spring of the year (March and April) with no documented spawning in the fall. Therefore, a distinctive year class of oysters is revealed in **Table 4-3** where larval presence from March to May follows egg development and spawning, and spat and juvenile oysters are present from April to August. Because oysters in south Florida usually live 2 to 3 years, adults are present throughout the year. Oysters are known to spawn in south Florida from March to September, however, Wilson's work shows that if protracted spawning occurs, the sampling device (oyster shell hanger) does not document significant spat recruitment beyond the spring.

Information compiled in **Table 4-3** was used to develop a model of salinity tolerances for each oyster life stage during their presence in the estuary (Haunert and Konyha 2004). To reduce the variability of salinity, a daily mean salinity value is used as input. Salinities were calculated at locations where oysters were known to occur for the base case study and alternative flows using salinity models described in **Chapter 6**. Initial model runs were made using daily salinities that occurred two years prior to the field survey of Loxahatchee oysters in November 2003 which documented the horizontal distribution of oyster reefs and the size class and density of oysters. Based on the sizes and the approximate growth rates of local oysters, all live oysters were assumed to be less than two years old. The purpose of these model runs was to ascertain the frequency and magnitude of stress, harm, and mortality for each life stage throughout the oyster's upper and middle estuary distribution (RM 4 to RM 6) during the last two years. The frequency and magnitude of stressful conditions at each location was paired with the density of oysters at that location to determine the quantitative relationship between these factors. Once this relationship was documented, it was added to the model to allow long term (35 years) simulations of oyster distribution and densities for the base case and alternative flow scenarios. This method would therefore permit a comparison with the base case that quantitatively reveals if the suitability of the oyster habitat increased or decreased with the flow alternatives.

Table 4-3. Salinity Tolerances During Life Stages of the American Oyster.

Life Stage	Salinity (ppt)	Duration (days)	J	F	M	A	M	J	J	A	S	O	N	D	Reference
Eggs			X	X	X	X									**Wilson et al. 2004**
Harm	7.5 - 10.0	1													**Burrel 1986**
Mortality	0.0 - 7.5	1													**Burrel 1986**
Larvae					X	X	X								**Wilson et al. 2004**
Stress	10.0 - 12.0	1													**Loosanoff 1965; Davis 1958**
Harm	0.0 - 10.0	1													**Davis 1958**
Mortality	0.0 - 10.0	14													**Davis 1958**
Spat & Juveniles						X	X	X	X						**Wilson et al. 2004**
Stress	5.0 – 10.0	1													**Ray and Benefield 1997**
Harm	0.0 -5.0	1													**Loosanoff 1953**
Mortality	0.0 – 5.0	7													**Volety et al. 2003**
Adults			X	X	X	X	X	X	X	X	X	X	X	X	
Stress	7.5 - 10.0														**Woodward-Clyde 1998**
Harm	5.0 – 7.5	1													**Loosanoff 1953, 1965**
Mortality	2.0 – 5.0	28													**Loosanoff 1953; Volety et al 2003**
Mortality	0.0 – 2.0	14													**Roesijadi 2004**

POLYHALINE ZONE VEC: SEAGRASSES

Justification

Biological productivity and diversity in many estuarine systems is dependent upon healthy seagrass populations. The presence of healthy seagrass beds results in a diverse, dense and productive faunal community (Gilmore 1995; Lewis 1984; Thayer et al. 1984; Virnstein et al. 1983). Seagrass beds provide food for bacteria and microscopic animals at the base of a complex food web, as well as, food for larger organisms such as green turtles and manatees. Seagrasses offer a refuge and nursery for numerous commercially and recreationally important species including shrimp, fishes and crabs and their prey (Zieman 1982; Phillips 1984; Thayer et al. 1984; Kenworthy et al. 1988; Zieman and Zieman 1989; Sogard et al. 1989). The majority of landed commercial and recreational fish spend at least some portion of their life history using seagrass beds. Seagrass beds enhance water quality (Fonseca et al. 1983; Fonseca and Fisher 1986; Fonseca 1989; Fonseca and Cahalan 1992) by providing an ideal substrate for periphyton that assimilate dissolved nutrients while the leafy seagrass canopy baffles waves and currents thus inhibiting resuspension of fine particles and trapping sediments (Ward et al. 1984).

Salinity thresholds documented in literature or observed in unpublished studies are presented as Performance Measures for shoal grass (*Halodule wrightii*), manatee grass (*Syringodium filiforme*), and turtle grass (*Thallasia testudinum*). There are limited data available on salinity thresholds for Johnson's seagrass (*Halophila johnsonii)*, a threatened species currently abundant in the Loxahatchee Estuary. Accordingly, the best available salinity data will be used to help assess potential impacts to this threatened species. Available salinity tolerance information was used to infer levels of stress to the seagrass communities for comparison of alternative flow scenarios. The levels of stress used for the seagrass evaluation are no stress, potential stress, harm, and mortality (see **Chapter 5** for discussion of evaluation methodology).

Distribution

Several seagrass mapping efforts have been conducted in the Loxahatchee Estuary (**Table 4-4**). Mapping techniques have ranged from outlining seagrass signatures on mylar over photographs and matching (best fit) this linework to base maps to the more precise technique of simultaneously interpreting/rectifying the habitat polygons using an analytical stereoplotter. Because of inconsistencies in mapping methods, all seagrass mapping data do not exhibit the same positional accuracy; therefore, caution should be used in comparing exact positions and acreages. However, general comparisons of the various maps provide a good indication of where persistent seagrass beds exist and areas of greatest change over time. Available seagrass maps were reviewed along with associated reports and are summarized below.

Table 4-4. Summary of Seagrass Mapping Studies of the Loxahatchee Estuary.

Year	Map Area	Mapping Methods	Lead Agency	Apparent Seagrass Gains/Losses	Reference
1980 -1981	Embayment to Inlet	Seagrass signatures outlined on photo overlay based on limited groundtruthing then "best fit" to base map.	USGS		McPherson et al. 1982
1985	River forks and Embayment to inlet and south end of Indian River Lagoon	Detailed groundtruthing, linework "best fit" to 1970 property appraisal composite photograph.	Palm Beach County Health Department	Gain	Klemm and Vare 1985
1990	River forks and Embayment	Groundtruthing results mapped onto aerial photos using bearings to local landmarks.	Jupiter Inlet District (JID)	Loss	Law Environmental Inc. 1990
1994	River forks and Embayment	Groundtruthing with GPS to confirm signatures on aerial photo signatures.	JID	No change	Applied Technology and Management, Inc. 1994
1996	River forks and Embayment	Groundtruthing with GPS to confirm aerial photo signature; edges of grass beds were surveyed using GPS.	JID	Significant loss	Cutcher 1999
1998	River forks and Embayment	Groundtruthing with GPS to confirm aerial photo signature; edges of grass beds were surveyed using GPS.	JID	Slight gain	Cutcher 1999
2000	Embayment and entrances to 3 tributary forks	Groundtruthing with GPS to confirm aerial photo signature; edges of grass beds were surveyed using GPS.	JID	Gain	Cutcher 2000
2003	Embayment and entrances to 3 tributary forks	Groundtruthing with GPS to confirm aerial photo signatures; analytical stereoplotter.	LRD/ SFWMD	Gain	Avineon, Inc. 2003
2003-2004	Upstream of the A1A bridge to RM 6.5	Species-specific map based on detailed groundtruthing with GPS.	LRD/ SFWMD	Gain in manatee grass since 1985	Loxahatchee River District 2004

For this plan, the SFWMD had 1980-81, 1985, and 2003 seagrass data prepared in Geographic Information System (GIS) format for general comparison. Maps from these data are presented below. The other maps referenced in **Table 4-4** were reviewed along with associated reports but were not available in GIS format; consequently, they are summarized below but not presented in graphic format.

Early 1900s - 1969

Prior to stabilization in 1947, the Jupiter Inlet periodically opened and closed. Anecdotal information indicates that seagrasses were present in the estuary at times when the inlet was open but specific locations and species composition are not known (Cary Publishing, Inc. 1973). After the inlet was stabilized in the 1940s and salinity and water clarity became favorable, it is likely that seagrasses were persistent in the estuary. Additional anecdotal information indicates that seagrass beds “thrived” from 1957 to 1969 along the west shore of the Northwest Fork approximately 0.5 mile upstream of Pennock Point (McPherson et al. 1982; see note on **Figure 4-15**). If seagrasses thrived in this reach of the Northwest Fork, it is likely that they also thrived downstream in the Central Embayment during that time period.

1980 – 1985

The first known seagrass map of the Loxahatchee Estuary was prepared in 1980/81 by the United States Geological Survey (USGS; McPherson et al. 1982). A hard copy of this map was digitized and is shown in **Figure 4-15**. The 1980/81 map shows seagrass coverage within and downstream of the Central Embayment, but not within the river forks. It is unclear whether this survey included the forks or if the forks were inspected and no seagrasses were present.

Although the 1980/81 map does not depict species distribution, detailed text published with the map indicates that shoal grass was the dominant species and manatee and turtle grass were rare. The map text also indicates that *Halophila* was sometimes found growing with shoal grass, but the species of *Halophila* was not noted.

In 1985, the Palm Beach County Heath Department mapped Loxahatchee seagrasses (Klemm and Vare 1985). This effort included species mapping. A hard copy of the 1985 map was digitized and is presented in **Figure 4-16**. The same species observed in 1980/81 were documented in 1985. As with the 1980/81 mapping effort, shoal grass was the dominant species with manatee and turtle grass being relatively rare in the Central Embayment. The 1985 map showed seagrasses farther up the Northwest Fork than the anecdotal note mentioned above for the 1957-1969 time period. Additionally, there was apparently significant seagrass loss in the middle of the Central Embayment (south side of the sand bar) from 1980/81 to 1985.

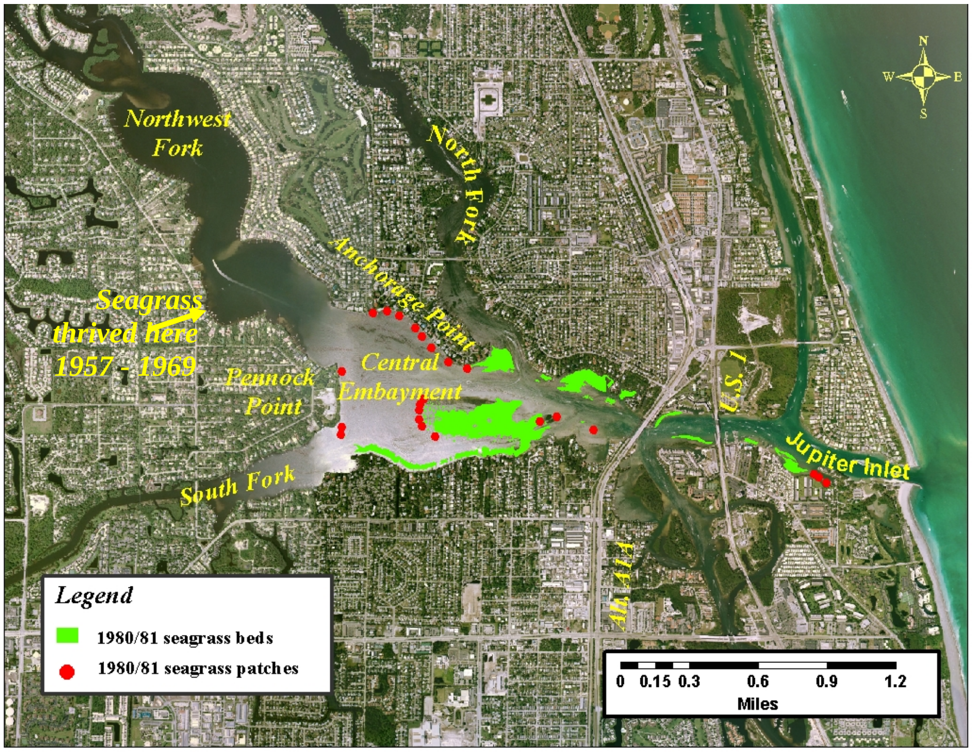

Figure 4-13. 1980/1981 Map of Seagrass Distribution (Source: McPherson et al. 1982).

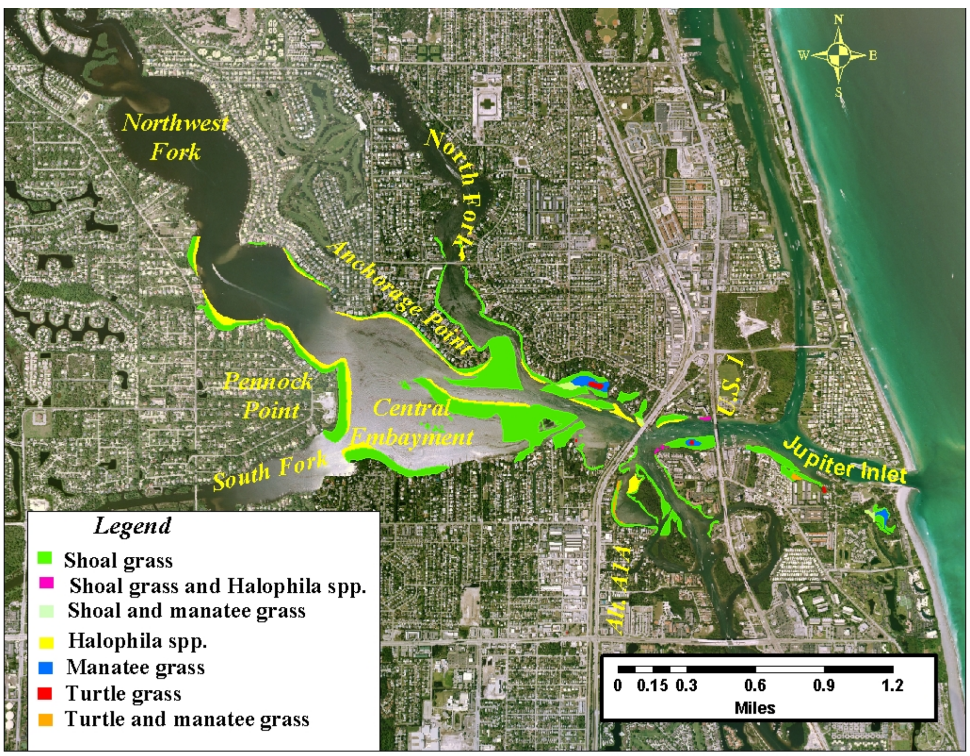

Figure 4-14. 1985 Map of Seagrass Distribution (Source: Klemm and Vare 1985).

The 1980/81 map included bathymetric contours. A visual comparison of the bathymetric contours with the deep edges of the seagrass beds revealed that Loxahatchee Estuary seagrass beds were quite shallow in the early 1980s. Seagrasses rarely extended deeper than the 4 foot (mean sea level) contour line. Klemm and Vare (1985) noted that seagrass growth in 1985 was also restricted to only the shallower areas of the estuary. They indicated that freshwater flows from the Northwest and South Forks were observed to be “turbid and stained with tannin resulting in significantly reduced light penetration restricting the growth of submerged grasses to only the shallower areas.” They noted visibility of 20–30 feet near the inlet but only 3–4 inches in the western reaches of the Central Embayment and in the forks. As would be expected, they found the densest seagrass beds closest to the Jupiter Inlet with the best water clarity and tidal flushing and the sparsest beds in areas of poor water quality and decreased light penetration.

1985 – 1990

The Jupiter Inlet District (JID) began mapping seagrasses in 1990. To date, they have mapped Loxahatchee Estuary seagrasses in 1990, 1994, 1996, 1998 and 2000. In 1990, four species of seagrass were found: shoal grass, manatee grass, turtle grass, and *Halophila sp.* (Law Environmental, Inc. 1990). As with previous mapping efforts, shoal grass was the dominant species in the embayment, all seagrasses occurred in shallow areas, and the densest seagrass beds occurred near the inlet. Moving upstream from the railroad bridge, *Halophila* ended first and then turtle and manatee grass. Trace amounts of manatee grass were found along the west bank of the Northwest Fork.

Significant changes in seagrass distribution and acreage occurred from 1985 to 1990 (Law Environmental, Inc. 1990). Seagrass losses exceeded gains. Losses were attributed to reduction in acreage within the North and Northwest Forks (beds receded downstream) and Central Embayment (beds became dissected into isolated patches). The only important gain noted was in the vicinity of the railroad bridge; an area strongly influenced by oceanic water entering through the inlet. Species composition changes were also noted. The deep edge *Halophila* fringes observed in 1985 were no longer present in 1990. Manatee grass apparently moved up river to Anchorage Point and expanded into former shoal grass areas.

1990 – 1994

Seagrass coverage in most areas of the estuary did not change much between 1990 and 1994. However, there was a distribution change in the sand bar area. The sand bar seagrass bed observed in 1990 was still present in 1994, however it apparently shifted slightly to the south and west. Accretion on the sand bar may be partly responsible for the shift (Applied Technology and Management, Inc. 1994). Four seagrass species were observed: shoal grass, manatee grass, turtle grass, and Johnson’s seagrass. The 1994 map was the first report to document the presence of Johnson’s seagrass in the Loxahatchee Estuary. This threatened species was observed throughout the Central Embayment in 1994 (Applied Technology and Management, Inc. 1994).

1994-1998

A large loss of seagrass occurred from 1994 to 1996 (51%) with an apparent slight recovery (10%) from 1996 to 1998 (Cutcher 1999). The high rainfall in 1994/1995 may have increased freshwater flows and reduced water clarity, contributing to the apparent seagrass decline. The increases in acreage observed from 1996 to 1998 were largely in the eastern section of the embayment. Shoal grass continued to be the dominant species from 1994 to 1998. Cutcher (1999) was the first report that specifically mentioned the presence of paddle grass (*Halophila decipiens*). Both paddle grass and Johnson's seagrass were considerably less abundant than shoal grass.

1998 - 2000

Cutcher (2000) reported a 22% increase in seagrass coverage between 1998 and 2000. The increase in seagrass coverage occurred in both the eastern and western portions of the embayment. Shoal grass continued to be the dominant seagrass species. Cutcher (2000) suggested that the general drought conditions in the spring and summer of 2000 may have contributed to overall improvement in water quality and subsequent increases in seagrass coverage.

1998 – 2002 (Lower Embayment)

The Loxahatchee River District (LRD) conducted detailed mapping and monitoring in the south end of the Indian River Lagoon in 1998, 2000, and 2002 (Riddler et al. 1999, 2000, 2003). These studies included the most downstream portion of the Loxahatchee Estuary from the inlet to one and a half miles west of the inlet. Based on the LRD reports, seagrasses in this area continue to increase in density and composition. The density of Johnson's seagrass substantially increased over time. The LRD concluded environmental conditions in the section of the Loxahatchee Estuary closest to the inlet were favorable for multiple seagrass species to exist.

2003/2004

In 2003, the South Florida Water Management District issued a contract to map Loxahatchee Estuary seagrasses using the same mapping method used for mapping the adjacent Indian River and Lake Worth Lagoons (**Figure 4-17**). This method uses true color aerial photography, groundtruthing with GPS, and mapping using an analytical stereoplotter. The goal of the 2003 mapping effort was to map Central Embayment seagrasses and the lower portions of the river forks (photo boundaries are shown on **Figure 4-17**).

A visual comparison of the 2000 and 2003 maps revealed a slight increase in seagrass coverage throughout the estuary. A comparison of the 2003 seagrass coverage with current bathymetric data was consistent with conclusion from the earlier mapping efforts; the average deep edge of the seagrass beds is shallow (approximately 3 feet below mean sea level).

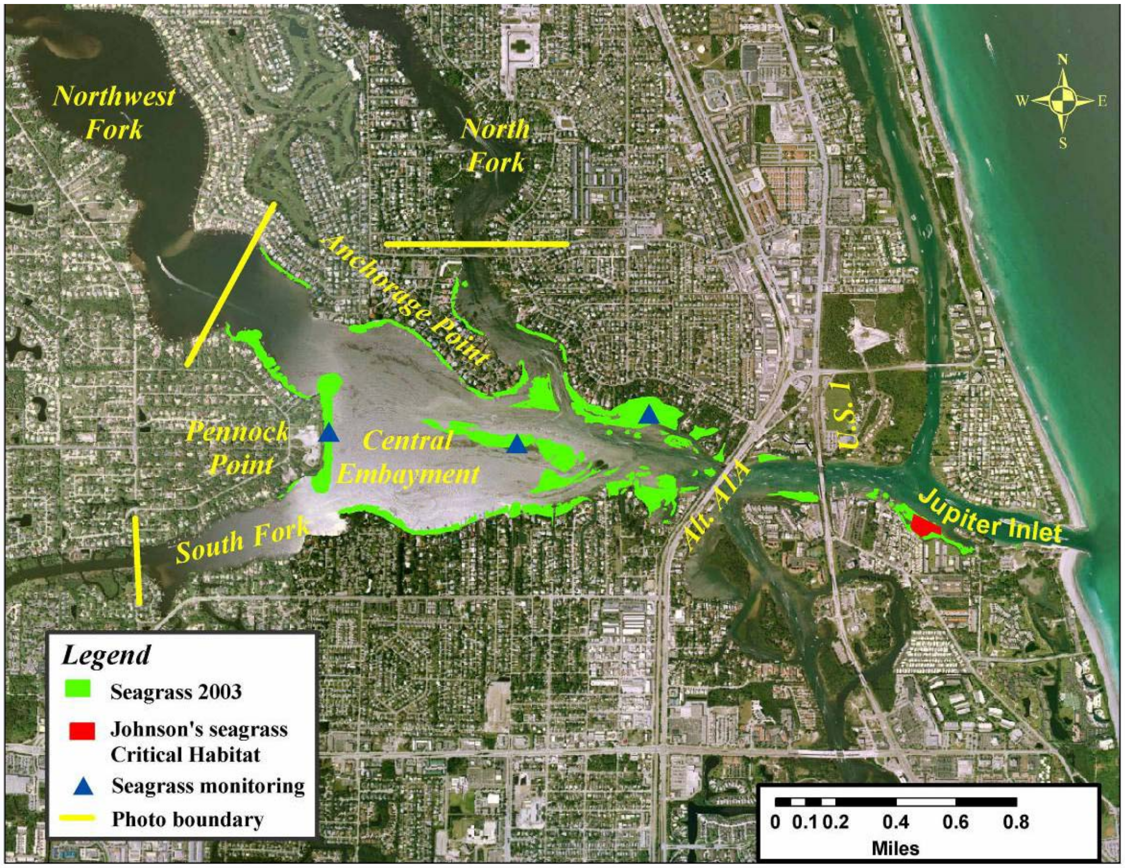

Figure 4-15. 2003 Seagrass Map Prepared from Aerial Photographs (Source: Avineon, Inc. 2003).

To supplement the 2003 mapping from aerial photography, the SFWMD partnered with the Loxahatchee River District to prepare a species-specific seagrass map (**Figure 4-18**; Loxahatchee River District 2004). The species-specific map was prepared in 2003/2004 using detailed groundtruthing with sub-meter accuracy, differentially corrected, GPS unit to document seagrass bed locations.

The groundtruthing effort for the species specific mapping effort revealed that seagrass beds existed upstream of the photography boundaries used for the 2003 mapping effort. Seagrass beds were found up river to approximately RM 3.4 and occasional patches of seagrasses were found near RM 4.0. The seagrass species found within the Northwest Fork included shoal grass and Johnson’s seagrass.

Through the Loxahatchee River District’s mapping effort, all seven species of seagrasses found in South Florida were documented in the Loxahatchee Estuary: shoal grass, manatee grass, turtle grass, paddle grass, Johnson’s seagrass, star grass, and widgeon grass. The LRD’s survey is the first to document the presence of star grass and widgeon grass in the Loxahatchee Estuary. This survey agreed with previous studies which indicated that shoal grass is the dominant seagrass species in the Loxahatchee Estuary. Detailed maps prepared for each species can be found in the map report prepared by the LRD (Loxahatchee River District 2004).

The only other known species-specific seagrass map of the Loxahatchee Estuary is the 1985 map (Klemm and Vare 1985). A comparison of the 1985 and 2003/2004 maps revealed that shoal grass was the dominant species and occurred throughout the estuary on both maps. Turtle grass was present in the same location on both maps; the cove on the north side of the estuary approximately 0.3 miles upstream of Alternate A1A (North Bay site). *Halophila* was documented throughout the estuary in both efforts, but species of *Halophila* were only differentiated in the 2003/2004 map. The biggest difference in species distribution was the presence of manatee grass farther upstream in 2003/2004. In 1985, the upstream limit was the North Bay site. In 2003/2004 manatee grass occurred upstream to Anchorage Point and was found in the middle of the embayment across from Anchorage Point.

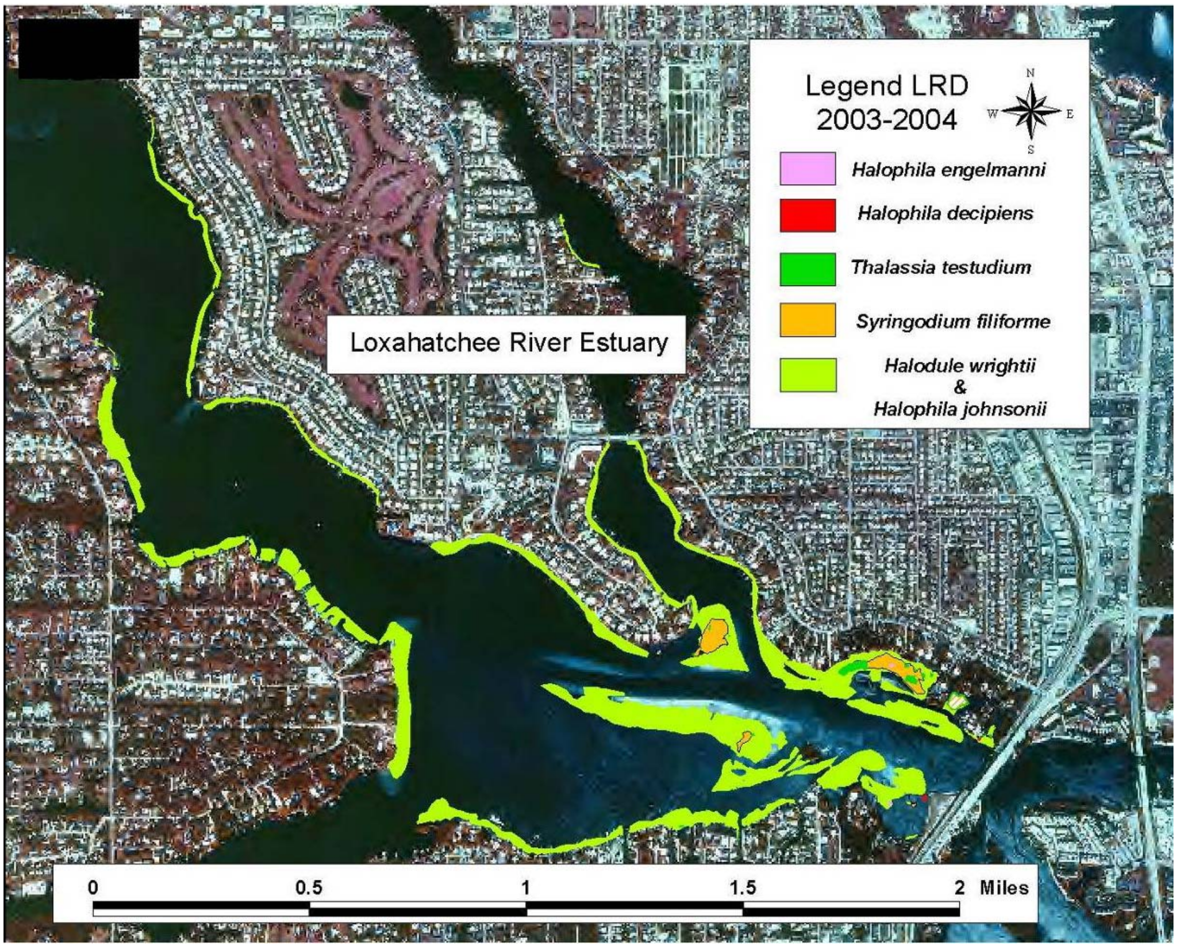

Figure 4-16. 2003/2004 Map of Seagrass Species in the Loxahatchee Estuary. Widgeon Grass was found near River Mile 6.5 and is not shown on this map. (Source: Loxahatchee River District 2004)

Seagrass Monitoring

In the summer of 2003, the SFWMD and the LRD partnered to conduct detailed monitoring of seagrasses within the embayment of the Loxahatchee River. The monitoring sites are shown on **Figure 4-17**. The purpose of this study is to document seasonal changes in seagrass and associated macroalgae (epiphytes, attached algae, and drift algae) over a 3-year period. Data collected will be used to better understand: (1) the natural seasonal variability of seagrass and macroalgae in the study area; and (2) the response of the seagrass community to freshwater flows. Water quality data also will be collected to evaluate potential links between water quality (particularly salinity, light, and chlorophyll) and trends in seagrass and algae. Preliminary results of the first year of monitoring are under review.

Summary/Discussion

It is likely that seagrass beds have been persistent features in the Loxahatchee Estuary since the late 1940s when the Jupiter Inlet was stabilized. Seagrass beds have been mapped numerous times from the late 1980s to present. Expansions and contractions of the beds have occurred over time but the core seagrass beds have persisted. Seagrass beds in the Loxahatchee Estuary tend to be most dense and diverse near the inlet and become less diverse and less dense at upstream locations. The upstream limit of seagrass beds appears to be near RM 3.0, with occasional patches of shoal and Johnson’s seagrasses upstream to near RM 4.0.

Shoal grass has been the dominant seagrass species in the estuary since at least the early 1980s. All species of seagrasses typically grow only in very shallow waters of the Loxahatchee Estuary. It is likely that the dark waters flowing from the river forks reduce light penetration through the water and limit the deep edge of the seagrass beds.

Dent (2000) states that salinity in the Loxahatchee “experiences significant shifts” due to freshwater flow from the watershed, flows through control structures, and tidal influence of ocean waters entering the estuary through the Jupiter Inlet. These dynamic salinity conditions may help explain the dominance of shoal grass in the estuary since this species tends to exhibit a broader salinity tolerance and ability to tolerate broad salinity fluctuations better than manatee grass, turtle grass, and the *Halophila* species (McMillan 1974). These salinity fluctuations are less extreme at sites closest to the inlet where seagrass species diversity and density is the greatest.

Due to the dynamic nature of the Loxahatchee Estuary, we can expect seagrass distributions to continue to expand and contract with changes in salinity. Continued periodic mapping of the seagrass beds using accurate and consistent methodology, in conjunction with the site specific monitoring being conducted by the LRD, will provide data which will help evaluate natural variability and assess impacts to seagrasses from freshwater flows.

Seagrasses are an important and persistent feature of the Loxhatchee River. However, the seagrasses in the Central Embayment already “exist near the edge of their tolerance” (Cutcher 1999). Consequently, it is important that careful consideration be given to any potential impacts that upstream restoration efforts may have on the seagrass resources in the Loxahatchee Estuary

Performance Measures

Salinity thresholds for seagrasses are used as polyhaline PMs. The salinity thresholds used in this plan were obtained from the literature or unpublished studies. Documented salinity thresholds were grouped into three performance measure categories: 1) no stress, 2) potential stress, and 3) stress. Salinities within the “no stress” category are expected to provide optimal conditions for the seagrasses; no adverse impacts are expected to occur when salinities occur within this category. Salinities at which impacts to seagrasses have been documented in either laboratory or field studies fall within the “stress” category. All other salinities were placed in a “potential stress” category for the performance measure evaluation. **Table 4-5** summarizes the salinity tolerances and identifies the salinity ranges within each stress category for each key seagrass species.

Table 4-5. Salinity Performance Measures for Four Species of Seagrasses[a].

Seagrass Species	Level of Salinity Stress	Salinity Threshold (ppt)	Justification for stress level	Reference
Shoal grass (*Halodule wrightii*)	No Stress	≥ 24	A literature review indicated that ≥ 24 ppt provided optimal conditions for shoal grass.	Woodward Clyde International Americas 1998
	Potential Stress	13 - 23	This represents the range between optimal conditions and documented stress.	
	Stress	≤ 12	Very little growth occurred between 6 and 12 ppt in a laboratory experiment; blade mortality occurred below 6 ppt.	Doering et al. 2002; McMahan1968
Manatee grass (*Syringodium filiforme*)	No Stress	≥ 23	A literature review indicated that ≥ 23 ppt provided optimal conditions for manatee grass.	Woodward Clyde International Americas 1998
	Potential Stress	16 to 22	This represents the range between optimal conditions and documented stress.	
	Stress	≤ 15	Two separate laboratory studies showed impacts at this threshold (in one experiment blade densities declined rapidly in another study leaf extension rates declined rapidly).	Unpublished SFWMD 1999; Lirman and Cropper 2003
Turtle grass (*Thallasia testudinum*)	No Stress	≥ 25	This value is based on optimal conditions stated in a literature review.	Woodward Clyde International Americas 1998
	Potential Stress	20-24	This represents the range between optimal conditions and documented stress.	
	Stress	≤ 19	In one study, limited growth was observed between 16-19 ppt and in another study photosynthesis decreased by one third at 18 ppt. Growth parameters were negatively impacted in a laboratory experiment at salinities between 6 and 12 ppt.	Woodward Clyde International Americas 1998; Doering and Chamberlain 2000
Johnson's seagrass (*Halophila johnsonii*)	No Stress	≥ 25	This value is based on optimal conditions stated in a literature review.	Woodward Clyde International Americas 1998
	Potential Stress	15-24	The documented range stated in the Final Recovery Plan for this threatened species is 15–43 ppt so this evaluation assumes that below optimal conditions and within the documented range there is potential for stress.	National Marine Fisheries Service 2002
	Stress	≤ 14	The documented range stated in the Final Recovery Plan for this threatened species is 15–43 ppt so this evaluation assumes that salinities below 15 ppt would be stressful for this threatened species.	National Marine Fisheries Service 2002

[a] Because this study evaluated impacts from reductions in salinities, only the lower limit of the "no stress" zone is included in this table.

In a few cases, the available literature and unpublished studies documented a duration associated with a salinity threshold that resulted in severe stress such as blade mortality. **Table 4-6** summarizes this information for each of the four key species. These salinity/duration data provide additional performance measures for each species.

Table 4-6. Salinity/Duration Performance Measures for Four Species of Seagrasses.

Seagrass Species	Salinity Threshold (ppt)	Justification for "severe stress"	Reference
Shoal grass (*Halodule wrightii*)	< 6 ppt for 30 days; 3.5 ppt for 21 days	Blade mortality occurred at these salinities in laboratory experiments.	Doering et al. 2002; McMahan 1968
Manatee grass (*Syringodium filiforme*)	≤ 15 ppt for 26 days	In a lab experiment, blade densities declined rapidly after 26 days. Additionally, field observations revealed that after six weeks of salinities < 15 ppt blade mortality occurred.	Unpublished SFWMD 1999; Dan Haunert, personal observation.
Turtle grass (*Thallasia testudinum*)	≤ 4 ppt for 7 days	Based on one laboratory experiment no green material was left after a few days at 5 ppt, however, a more recent study showed survival at 5 ppt after 2 weeks (although leaf elongation was reduced). A literature review indicated a short-term (up to about 7 days) limit of 4 ppt; this limit is used for this evaluation.	McMillan 1974; Lirman and Cropper 2003; Woodward Clyde International Americas 1998
Johnson's seagrass (*Halophila johnsonii*)	5 ppt for 3 days	Blade mortality occurred at this salinity in a laboratory study.	Dawes et al. 1989

Although none of the available studies used to develop the above stress categories were conducted in the Loxahatchee Estuary, data from these studies provide the best available information for this preliminary evaluation. These performance measures will allow a consistent comparison of model runs to assess potential impacts of proposed upstream restoration efforts on the seagrass resources.

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Determining Hydroperiods and Flow Requirements in the Riverine Floodplain

The riverine floodplain from the Riverbend Park (RM 15.4) to Trapper Nelson's (RM 10.5) is mostly populated by a desirable mix of canopy and understory vegetative species. This reach of the river is generally considered a good quality functional ecosystem typical of riverine floodplains although a recent vegetation survey did document the migration of hammock and upland plant species into swamp areas (**Chapter 3**). Since of one of the guiding principles of the restoration plan is that no element of the ecosystem will be enhanced at the expense of another, it is critical that any adjustments in water management and delivery for restoration of the tidal floodplain must cause no harm to the riverine floodplain. Where possible, it is desirable to incorporate the hydrologic requirements for riverine swamps and hydric hammocks to enhance the ecological function of the riverine system.

The ecological health of the riverine floodplain is largely determined by regional hydrologic conditions and how much flow is delivered from the Lainhart Dam. There are four critical hydrologic factors that heavily influence the integrity of the vegetative community types that exist in the riverine floodplain of the Northwest Fork. These are the maximum dry season water elevations in the river channel, the minimum wet season water elevations in the floodplain, the durations of each, and the water stages over the floodplain during the transitional periods. An effective restoration strategy must provide a mechanism and a management plan for each of these factors. Management of flows from the upstream areas is the primary mechanism by which the critical hydrologic factors can be manipulated to achieve restoration goals. However, the relationship between river stage/floodplain inundation and volume of water being delivered to the system from upstream areas is not yet known. The objective of this chapter is to determine the hydroperiod and flow requirements of the riverine floodplain plant species through a series of measurements and field observations of river and floodplain stages and flows over Lainhart Dam. Based on this information, it is anticipated that hydrologic regimens developed for the Northwest Fork of the Loxahatchee River Restoration Plan will not cause any degradation of the riverine floodplain species and may, in fact, enhance the overall health of the ecosystem.

HABITAT QUALITY EVALUATION

The quality of the riverine floodplain community was documented on August 19, 2004 by a team of wetland scientists, biologists and engineers as a part of the ecological benefit/impact analyses of the North Palm Beach County-Part I project. Wetland Rapid Assessment Procedures (WRAP; Miller and Gunsalus 1997) were utilized in the functional assessment of the proposed ecosystems. WRAP is an established methodology for assessing a wetland/ecological community that takes into account the overall quality of an ecosystem through a process of rating a number of predefined variables. WRAP has been statistically validated with respect to repeatability and the measurement of independent variables. It is currently used by the United States Army Corps of Engineers (USACE) in the State of Florida as part of the 404 Regulatory Permitting process. It was also used locally in the "Loxahatchee River Basin Wetland Planning Projects for Martin and Palm Beach Counties" (Treasure Coast Regional Planning Council 1999; Martin County Growth Management Department 2000). The final WRAP score for a given area is a numerical value between 0 and 1, with 0 representing no functional value and 1 representing a system functioning at a very high level.

The habitat quality of the Northwest Fork riverine floodplain communities was assessed using WRAP for four transects established perpendicular to the river channel across the floodplain (**Figure 5-1**). These transects are located in the upstream portions of the riverine reach of the Northwest Fork and are not influenced by saltwater intrusion from intertidal mixing as are transects located further downstream. The assessment team's field observations of the different community types as well as the assigned WRAP score and justifications are described in the following discussion. More descriptive information can be found in "Procedural Approach for Ecological Benefit and Impact Analyses of Alternative Plans: North Palm Beach County Part I Watershed Wetlands" (Draft Final Report, in prep).

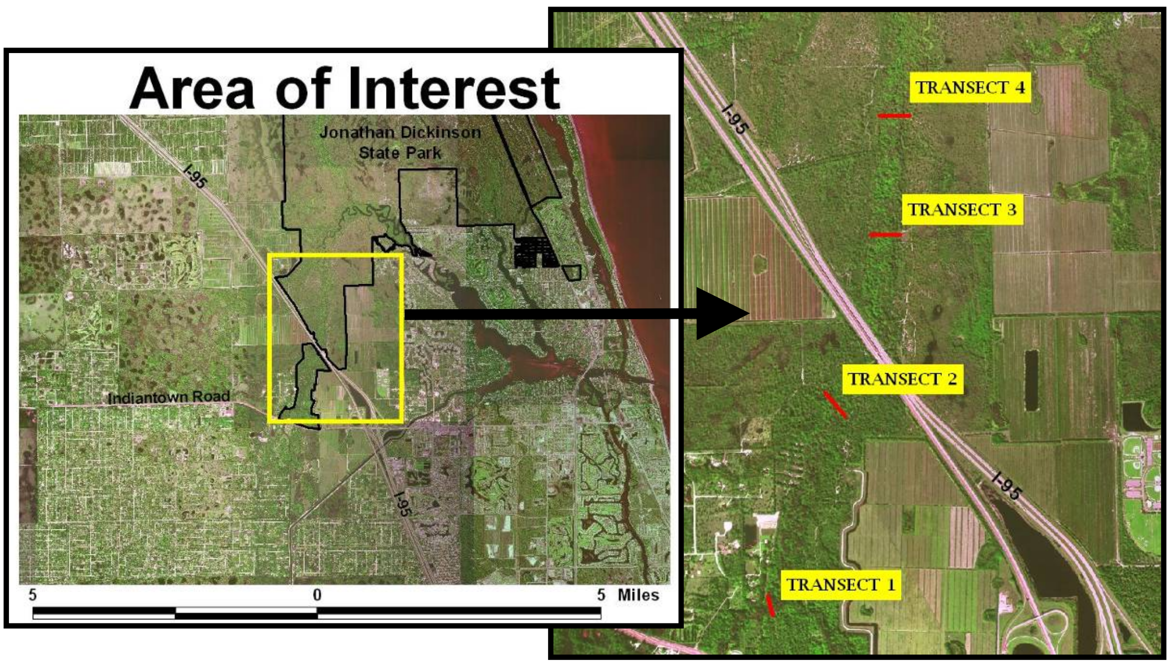


Figure 5-1. Riverine Reach of Northwest Fork of Loxahatchee River.

Evaluation Polygon #1 (NWF-1) represents the communities located upstream from Masten Dam and contains Transect 1 and Transect 2-1 (**Tables 5-1** and **5-2**). Transect 1 is located just downstream of Lainhart Dam (RM 14.5) whereas Transect 2-1 is located upstream of the western side of Masten Dam (RM 13.57). The vegetative communities within this polygon are intact, and are dominated by hydric hammocks and floodplain swamps. The floodplain forest canopy is well established and provides good habitat support for wildlife. When compared to historic conditions, the duration and frequency of inundation in the floodplain has decreased due to reduced freshwater flows to the Northwest Fork and low groundwater tables. Evidence of these hydrologic changes is present in the floodplain vegetation. Specifically, young age class cabbage palms have migrated into the lower elevations of the floodplain (approximately 0.3 ft) whereas the mature cabbage palms historically are associated with the higher elevations of the hydric hammocks. On-going vegetation monitoring will provide further information to use in the adaptive management process. This polygon received a WRAP score of 0.81.

Table 5-1. Wetlands Evaluation Summary of the Riverine Reach of the Northwest Fork of Loxahatchee River Upstream of Masten Dam at Transect 1 Using the Wetland Rapid Assessment Procedure (WRAP).

Natural Area:	Northwest Fork of the Loxahatchee River
Site:	Transect 1
Polygon Number:	NWF-1
Date of Visit:	08/19/04
Assessment Team Members Present:	B. Gunsalus (SFWMD); D. Roberts (FPS); J. Fisher (FPS); E. Cowan (FPS); P. Balci (E&E)
Dominant FNAI Community Type(s):	Floodplain Swamp; Hydric Hammock
Wildlife Utilization:	Score = 2.5; impacts on hydrologic deliveries; also slight impacts to the adjacent buffers providing habitat support for wildlife.
Wetland Overstory/Shrub Canopy:	Score = 3.0; dominated by desirable and appropriate plant species.
Vegetative Ground Cover:	Score = 2.5; mostly desirable species but exotic elephant ear (*Xanthosoma sagittifolium*) also present.
Adjacent Upland/Wetland Buffer:	Avg. Score = 2.56 External buffer score = 2.5 (Major roadway [Indian Town Road] 25%; Natural areas-75%) Internal buffer score = 2.62 (Jupiter Farms-25%; Natural areas-75%)
Field Indicators of Wetland Hydrology:	Score = 2.0; Hydroperiod duration is shortened and water delivery is controlled.
Water Quality Inputs and Treatment:	Score = 2.5; close to Jupiter Farms (~25%impacts)
Overall WRAP Score:	0.81
Other Comments	Ground level elevation data are available for Transects 1 and 2-1.

Table 5-2. Wetland Evaluation Summary of the Riverine Reach of the Northwest Fork of the Loxahatchee River Upstream of Masten Dam at Transect 2-1 Using the Wetland Rapid Assessment Procedure (WRAP).

Natural Area:	Northwest Fork of the Loxahatchee River
Site:	Transect 2-1; Canal 3
Polygon Number:	NWF-1
Date of Visit:	08/19/04
Assessment Team Members Present:	B. Gunsalus (SFWMD); D. Roberts (FPS); J. Fisher (FPS); E. Cowan (FPS); P. Balci (E&E)
Dominant FNAI Community Type(s):	Floodplain Swamp; Hydric Hammock
Wildlife Utilization:	Score = 2.5; hydrologic deliveries are shortened; also slight impacts to the adjacent buffers providing habitat support for wildlife.
Wetland Overstory/Shrub Canopy:	Score = 3.0; Hydric hammock is dominated by cabbage palm whereas pop ash and bald cypress are the dominant species in the floodplain swamp.
Vegetative Ground Cover:	Score = 2.0; some exotics <10% (i.e. *Syngonium podophyllum*) but dominated by native species (i.e. *Thelypteris interrupta*; *T. dentata*, *Acrostichum danaeifolium*)
Adjacent Upland/Wetland Buffer:	Avg. Score = 2.3 External buffer score = 1.8 (Old agricultural site-75%; Major roadway-Indian Town Road-25%) Internal buffer score = 2.8 (Indian Town Road-10%; Natural areas-90%)
Field Indicators of Wetland Hydrology:	Score = 2.0; Hydroperiod duration is shortened and water delivery is controlled
Water Quality Inputs and Treatment:	Score = 2.7 (LU=2.6; PT=2.8)
Overall WRAP Score:	0.81
Other Comments	Elevation data are available for Transect 2-1.

The second evaluation polygon (NWF-2) represents the communities located downstream from Masten Dam and includes Transect 2-2, Transect 3 and Transect 4 (**Table 5-3**). Transect 2-2 is located downstream of Masten Dam on the west side of the Northwest Fork of the Loxahatchee River (RM 13.43); Transect 3 is located approximately 0.7 miles downstream of I-95 and the Florida Turnpike on the east side of the river (RM 12.07); Transect 4 is located on the west side of the river at RM 11.18 approximately 0.7 miles upstream of Trapper Nelson's Interpretive Site. Similar to the first polygon, hydric hammock and floodplain swamp are the dominant community types observed within this polygon. Canopy is impacted by the presence of Old World climbing fern (*Lygodium microphyllum*) especially at Transect 3. Hydrologic impacts are similar to those observed in other floodplain transects and are caused by decreased freshwater flows and low groundwater tables at the regional scale when compared with historic conditions. The WRAP score for this polygon was 0.83.

Table 5-3. Wetland Evaluation Summary of the Riverine Reach of the Northwest Fork of the Loxahatchee River Downstream of Masten Dam for Transects 2-2, 3, and 4 Using the Wetland Rapid Assessment Procedure (WRAP).

Natural Area:	Northwest Fork of the Loxahatchee River
Site:	Transect 2-2, Transect 3 and Transect 4
Polygon Number:	NWF-2
Date of Visit:	08/19/04
Assessment Team Members Present:	B. Gunsalus (SFWMD); D. Roberts (FPS); J. Fisher (FPS); P. Balci (E&E)
Dominant FNAI Community Type(s):	Floodplain Swamp; Hydric Hammock
Wildlife Utilization:	Score = 2.5; habitat support (buffer) and water deliveries slightly impacted
Wetland Overstory/ Shrub Canopy:	Score = 3.0; Hydric hammock is dominated by cabbage palm whereas pop ash and bald cypress are the dominant species in the floodplain swamp.
Vegetative Ground Cover:	Score = 2.5; some feral hog impacts on ground cover within the hydric hammock
Adjacent Upland/ Wetland Buffer:	Avg. Score = 2.2 External buffer score = 1.8 (Old agricultural site-50%; Major roadway (I-95)-33%; Natural areas-17%) Internal buffer score = 2.5 (Natural areas-100%)
Field Indicators of Wetland Hydrology:	Score = 2.0; Hydroperiod duration is shortened; delivery of water controlled for anthropogenic activities.
Water Quality Inputs and Treatment:	Score = 2.7 (LU=2.6; PT=2.8)
Overall WRAP Score:	0.83
Other Comments	Elevation data are available for Transects 2-1, 3 and 4.

The existing canopy and understory vegetative species composition is documented in the Transect Vegetation Summaries provided in **Chapter 3** of this document.

HYDROLOGIC EVALUATION OF THE RIVERINE FLOODPLAIN

Development of the evaluation methodology for riverine floodplain hydrology began with a list of assumptions that are put forth and universally agreed to as the fundamental common basis of an evaluation strategy. The fundamental driving assumption for the rest of the restoration effort is that the portion of the Northwest Fork from Riverbend Park to Trapper Nelson's currently has a healthy vegetative community typical of a riverine floodplain system (confirmed during WRAP evaluation) and that any restoration option considered for the lower reaches of the Northwest Fork and the rest of the Loxahatchee River and Estuary will in no way adversely impact, harm, or compromise the biological health and integrity of the riverine floodplain ecosystem.

Other assumptions are as follows:

- For this analysis, the riverine reach of the Northwest Fork floodplain extends from Riverbend Park (RM 15.4) to Trapper Nelson's (RM 10.5).
- There are no salinity issues that need to be addressed in this portion of the watershed. However, at sites below Masten Dam tides may cause fluctuations in water depth.
- The current stage/flow rating curve for Lainhart Dam is accurate and seepage around the structure is negligible (see Gonzalez, June 2004, Rating Improvements for Lainhart Dam, SCADA & Hydro Data Management, Technical Publication SHDM #1). This assumption needs to be reaffirmed following the major 2004 storm events.
- Existing (pre-Hurricane Frances) canopy vegetation represents desirable climax species; hydrologic conditions need to continue supporting the necessary recruitment and growth of these canopy species.
- Existing shrub and groundcover vegetation may not be appropriate and suitable adjustments in floodplain hydroperiod could be considered and implemented to create conditions favorable to maintain a more "typical" lower tier vegetative community.
- The predominant vegetative communities are the "Floodplain Swamps" and "Hydric Hammocks" as described in **Chapters 3** and **4.** Achieving hydrologic performance measures for "Floodplain Swamps" and "Hydric Hammocks" will concurrently meet the hydrologic performance measures for the entire floodplain community.

The evaluation methodology strategy depicted in **Figure 5-2** is based on the foregoing assumptions. It depicts the drivers that result in given river stages and the hydrologic constraints that, if exceeded, will result in adverse impacts to the existing system.

Ultimately, the hydrologic input and the resulting river/floodplain surface water stages must be consistent with the hydrologic needs of floodplain vegetative communities for the timing and duration of stage in the river and floodplain. To determine the hydrologic flow/stage response in the riverine floodplain, actual stage measurements in the river and floodplain under known flow conditions at Lainhart Dam were conducted. These measurements were taken at the vegetative Transects 1 through 4 which were established and surveyed in June and July 2003. Two types of field studies were conducted. The first was a controlled release study involving concurrent flow and stage measurement at the four transects for an entire tidal cycle with a nearly constant flow controlled at Lainhart Dam. The other type was an episodic field study with stage measurements at the four transects under varying flow conditions.

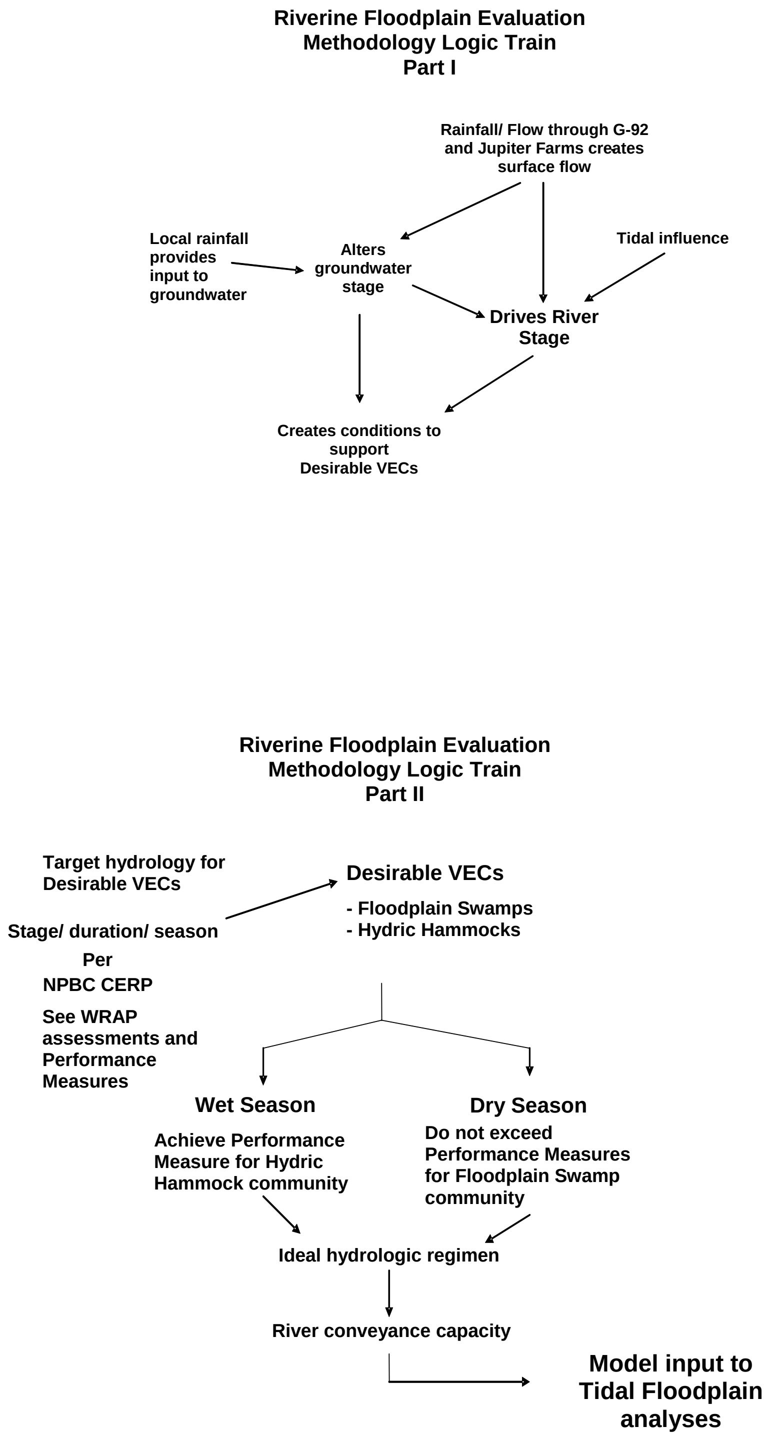


Figure 5-2. Riverine Floodplain Evaluation Methodology with Logic Train I and II.

CONTROLLED RELEASE STUDY

A controlled release study was performed on August 17, 2004 with water stage observations made at each transect during a continuous 12-hour period. The goal was to develop the stage/flow relationship in the river downstream of Lainhart Dam and make direct observations of water stages in the river channel and floodplain that would lead to identifying the maximum channel flow capacity during the dry season that would not adversely affect the floodplain vegetative community. The 12-hour duration of the measurements at Transects 2 and 4 allowed the direct observation of tidal influence on stages and flows at the most downstream portion of the protected riverine floodplain (Transect 4 at RM 11.18) and the most upstream portion of the riverine floodplain that would possibly be affected (Transect 2 at RM 13.43).

The controlled releases created a relatively constant flow at Lainhart Dam of between 80 cfs and 83 cfs. Simultaneous real time flow measurements were obtained in the river channel at Transects 1 through 4. The measurements were made by technicians from the SFWMD SCADA & Hydro Data Management Department. They were accompanied by wetland experts and staff members from the SFWMD, Florida Park Service (FPS) District 5 office, and other agencies. Gonzalez (2005) provides a full description of the study results and conclusions in SFWMD Technical Publication SHDM Report #2005-01. A copy of this document is included in **Appendix E**.

For this evaluation a high degree of confidence was required to confirm that the antecedent hydrologic conditions were representative of typical dry season patterns. Flow rate and river stage for the 4-month period (April 2004 –July 2004) prior to the controlled release study are depicted in **Figure 5-3.** During that 4-month period, flow over Lainhart Dam was typically less than 35 cfs and the river stage was lower than 11 feet NGVD. This pattern confirms that the stage and flow data collected during the controlled release study are indicative of normal dry season riverine floodplain responses to changing flows. The degree that tidal activity influenced water stages in this portion of the river also was evaluated. At Boy Scout Dock (RM 5.9) on August 17, 2004, low tides were at 5:45 am and 6:00 pm while high tides were at 11:12 am and 11:36 pm. Tidal range for the 12-hour period was from 0.1 feet to 2.4 feet NGVD.

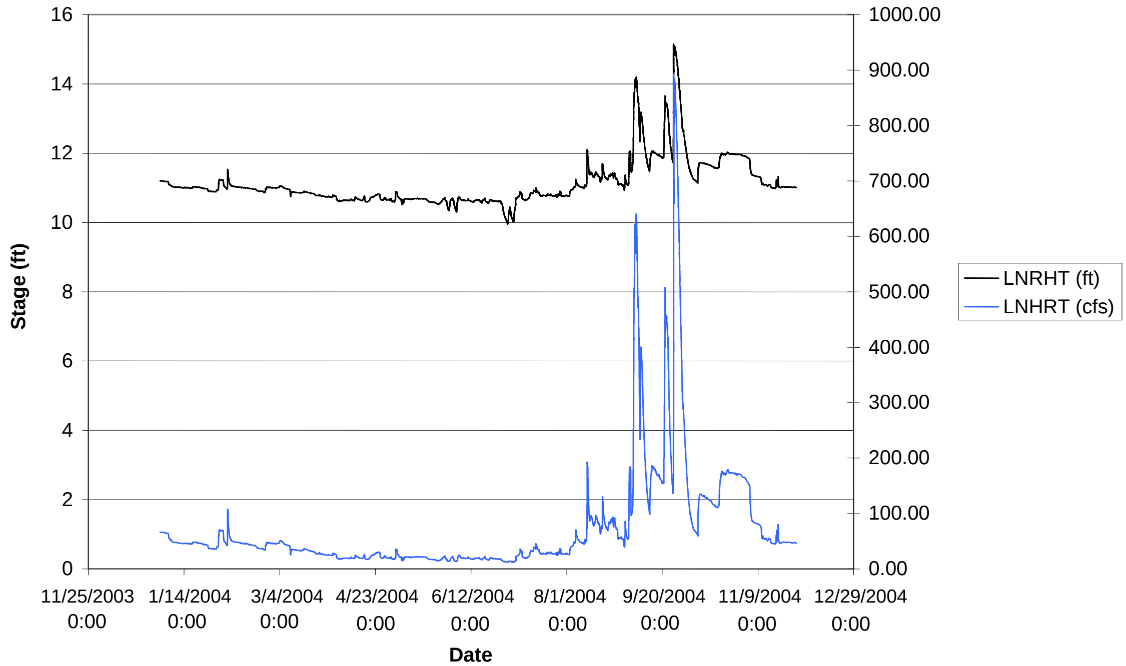


Figure 5-3. Northwest Fork River Stages (ft) and Flows (cfs) at Lainhart Dam from November 2003 to December 2004.

Measurement Procedures

Flow data were collected with a StreamPro acoustic profiler manufactured by RD Instruments (see **Figure 5-4)**. StreamPro is a small monostatic, four-transducer, 2400-KHz Acoustic Doppler Current Profiler (ADCP) mounted on a tethered platform. Stage measurements were made manually with conventional survey methods. Surveyed benchmarks were placed adjacent to the river channel at each transect. These benchmarks are identified by numbered metal tags. Transect 1 includes Tags 601, 602 and 609. Transect 2 includes Tags 603 and 606. Tag 607 is located at Transect 3; Tag 608 is located at Transect 4.

Figure 5-4. StreamPro 2400-KHz Acoustic Doppler Current Profiler (ADCP).

ADCPs measure the velocity of water, track water flow path, and measure channel depth as they move across the stream. ADCPs operate based on Doppler-shift principles using a proprietary broad-band acoustic signal processing algorithm for estimating the water velocity, flow depth, and bottom tracking. In an ADCP transect measurement the ADCP collects data at a frequency of about 1 Hz as it transects the river from one bank to the other, while operated via radio modem from a hand-held computer (**Figure 5-5**). The velocity, transect, and depth data are combined according to the velocity-area method, in a fashion similar to the traditional flow measurements by mechanical current meters described in the ISO Standard 748 (1997). ADCPs use "instantaneous" velocity profiles for computing flow instead of using one, two, or three point-velocity measurements as traditionally done in mechanical current-meter measurements. ADCPs are not able to measure water velocities near solid boundaries, near the free surface, nor very close to the instrument because of acoustic signal contamination. To estimate the unmeasured flow, the flow computation algorithm makes use of extrapolation routines. The total flow is computed as the summation of the measured flow and estimated flow.

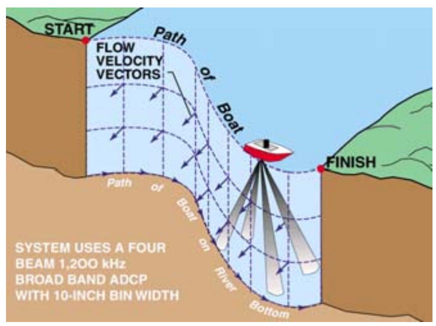


Figure 5-5. A Schematic of the Operation of a Broadband Boat-mounted, Four-transducer Acoustic Doppler Current Profiler (ADCP).

STEADY FLOWS

Stream flow measurements with the StreamPro under steady flow conditions were made following the guidelines developed by the USGS (2002a, 2002b) for estimating open-channel flows under steady flow conditions with a boat-mounted ADCP. These guidelines recommend estimating the streamflow as the average of four reciprocal transects (transects made on alternate directions) within 5% of each other; if this condition is not met, flow is estimated as the average of eight reciprocal transects.

TIME-VARYING FLOWS

Stream flow measurements of varying flows, such as tidally affected flows, are typically single transect estimates. Multiple samples can only be made by concurrently collecting transect data with several StreamPro ADCPs. Because four transects were being measured on August 17, multiple sample measurements could not be collected. Therefore, the USGS guidelines for operating ADCPs under steady flow conditions were observed during the four transect measurements.

Results and Observations

Data analyses and results of the controlled release study are discussed in detail in **Appendix D**. In summary, tidal range at RM 5.9 (Boy Scout Dock) during the controlled release study on August 17 was approximately 2.4 feet. The amplitude of the stage at Transect 4

(RM 11.8) was about 0.7 feet while at Transect 3 (RM 12.07), the stage varied only by about 0.1 foot. The bankfull capacity at Transects 3 and 4 can be estimated by combining the flow-at-Lainhart Dam against stage-at-transect curves with the direct stage-flow data collected at the transects for an inland base flow of about 80 cfs and a tidal amplitude of 2.5 feet at RM 9.1, and estimates of the bankfull stages. No observable tidal effects were found for river stages at Transects 1 and 2. Thus stage and flow are uniquely related at Transect 1 and 2, and the bankfull capacity of these sites can be estimated from the flow-at-Lainhart Dam against stage-at-transect curves. Flow at Lainhart Dam is the controlling factor of stage at Transects 1 and 2. Tidal influence and flow at Lainhart Dam are cofactors in stage at Transects 3 and 4. The bankfull channel capacities derived from these data under the studied tidal conditions were 98 cfs at Transect 1, 144 cfs at Transect 2, 110 cfs at Transect 3 and 100 cfs at Transect 4.

EPISODIC FIELD STUDY

During the period from July 27 through December 1, 2004, FPS and SFWMD staff recorded river surface stages at the four transects on several occasions. In each case, river stage was measured and the recorded flow at Lainhart Dam was noted. In some cases, rough measurements of submerged channel cross sections and flow velocities provided a rough estimate of actual flow volumes at the transect location itself. These flows were compared to the actual flow volume recorded at Lainhart Dam for the same period to confirm accuracy. Observations of the extent and depth of floodplain inundation were noted at the same time that these river stage observations and flow measurements were made.

Results and Observations

Table 5-4 lists the dates and transect locations where visual observations and measurements of water surface elevations were made, and the measured flow volumes (if any) when observations and measurements were made.

Table 5-4. Stages (ft) at Each Transect and Corresponding Flow (cfs) over Lainhart Dam for the Northwest Fork of the Loxahatchee River.

Date	Lainhart Flow (cfs)	T 1 (ft)	T 2-1 (ft)	T 2-2 (ft)	T 3 (ft)	T 4 (ft)
7/27/04	30	8.35				
8/3/04	38		7.71	4.73	2.48	0.89
8/12/04	114-139	10.46	8.56	7.20		2.53
8/13/04	88 - 95	9.79	8.19	6.31	3.83	1.42
8/17/04[a]	82 - 84	9.61 - 9.66	8.14 - 8.16	6.12 - 6.16	3.63 - 3.73	1.12 - 1.83
9/9/04	339		9.22			
9/10/04	236 - 241	11.54	8.78			
9/14/04	182 - 185				5.09	2.93
9/16/04	176	11.12			5.11	
9/23/04	288 - 325	11.88	9.25			4.04
9/29/04	461 - 476	12.69	9.82			5.08
10/1/04	258				5.94	

[a] This is the date of the Controlled Release Study; the data are provided as ranges.

The degree of floodplain inundation at different water stage levels is depicted in the following photographs and cross-sectional diagrams for each of the four riverine transects.

TRANSECT 1 (RM 14.5)

Figures 5-6 through **5-10** are photographs of the river and floodplain at Transect 1 taken during the observation period (July 27 - December 1, 2004) with flows ranging from 88 cfs to 476 cfs.

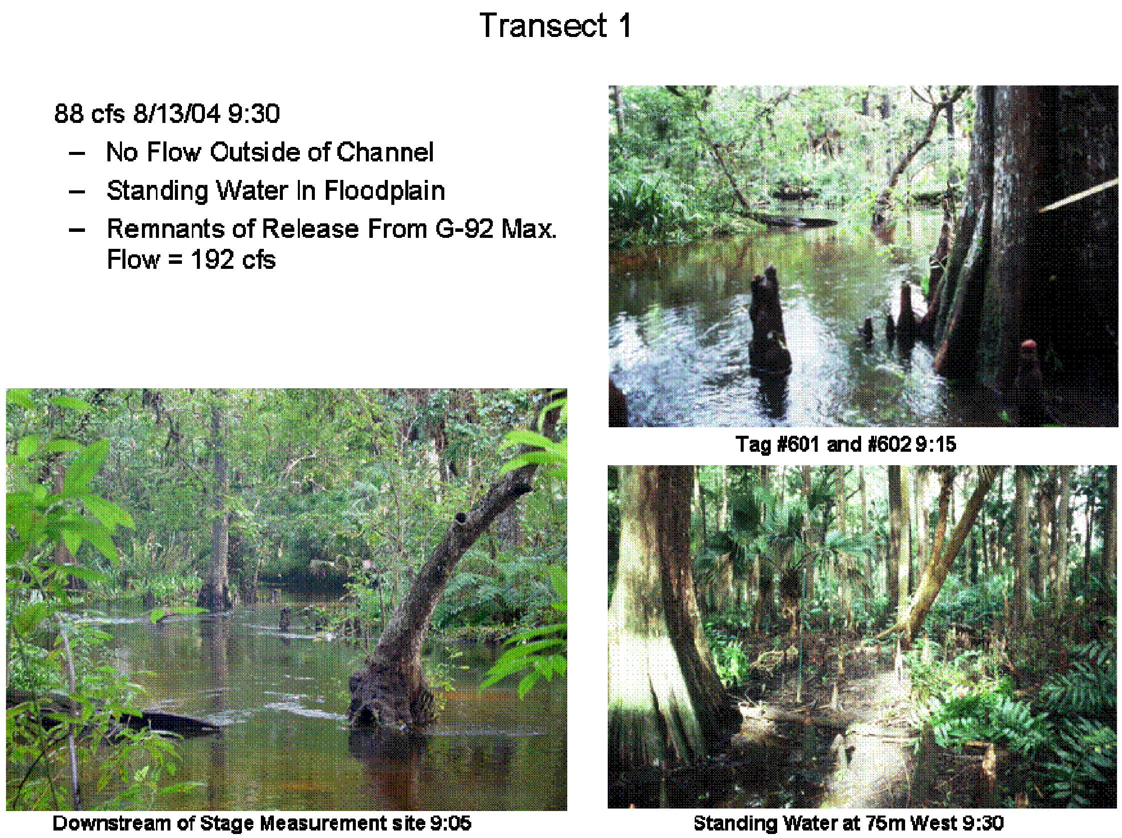


Figure 5-6. River Stage Conditions at Transect 1 on 8/13/04 with 88 cfs Flow at Lainhart Dam.

Transect 1

114 cfs 8/12/04 12:50 PM

- Water Level At Top of Bank
- Standing Water in Floodplain
- Debris Piled On Banks
- Ebbing Side of Controlled Release From G-92


Tag #601 and #602 12:00


Downstream of Stage Measurement Site and Tag #602 12:00


Standing Water at 75m West 12:15

Figure 5-7. River Stage Conditions at Transect 1 on 8/12/04 with 114 cfs Flow at Lainhart Dam.

Transect 1

241 cfs 9/10/04 10:40 AM

- Water Over Top of Bank
- No Visible Flow in Floodplain
- A Lot of Debris
- Floodplain Inundated Knee Deep


Floodplain Inundated at 75m West 10:50


Edge of Floodplain 10:30


Measuring Tag #601 10:45

Figure 5-8. River Stage Conditions at Transect 1 on 9/10/04 with 241 cfs Flow at Lainhart Dam.

Transect 1

288 cfs 9/23/04 2:52 PM

- Water Over Top of Bank
- Visual Flow in Floodplain
- Thigh Deep in Floodplain

Looking West at 55m East Pole 3:06

Edge of Floodplain at 45m West 2:45

Looking Downstream at Tag #601 2:52

Figure 5-9. River Stage Conditions at Transect 1 on 9/23/04 with 288 cfs Flow at Lainhart Dam.

Transect 1

476 cfs 9/29/04 10:18 AM

- Water Level at Top of Floodplain
- Waist Deep In Floodplain
- Few Cypress Knees Above Water Surface
- Flow Visually Observed in Floodplain

Edge of Floodplain Looking East 10:13

Looking Downstream at Tag #601 10:18

At 75m looking West 10:52

Figure 5-10. River Stage Conditions at Transect 1 on 9/29/04 with 476 cfs Flow at Lainhart Dam.

Figure 5-11 is a cross-sectional profile of Transect 1 based on the June 2003 survey data. The measured water stage elevations for each observation date. The depth and lateral extent of floodplain inundation is readily evident at each level of inundation. Flows are contained in the main river channel up to and through 88 cfs. That flow creates an associated river stage of approximately 9.4 feet NGVD. Water levels at that stage remain well below the lateral ground surface elevations in the floodplain.

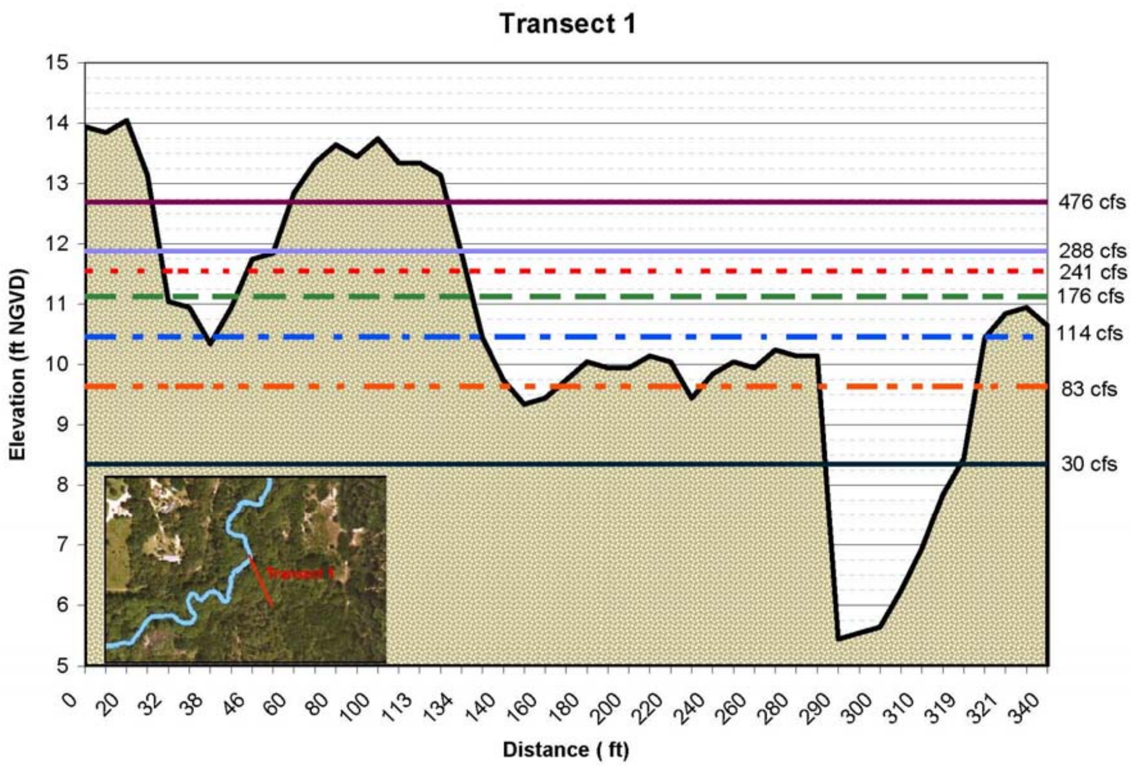


Figure 5-11. Transect 1 (RM 14.5) Cross Section and Observed Inundation Depth and Extent.

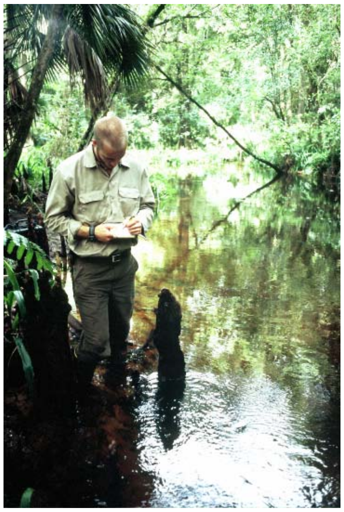
TRANSECT 2

Figures 5-12 through **5-16** are photographs photographs of the river and floodplain at Transect 2 taken during the observation period (July 27 - December 1, 2004) with flows ranging from 88 cfs to 476 cfs. Transect 2 has two segments. One segment (Transect 2-1) is upstream of Masten Dam and the other (Transect 2-2) is downstream of the dam.

Transect 2

89 cfs 8/13/04 10:15 AM

– River Flowing in Bank



Below Masten Dam Next to Tag #603 and Stream Flow Measurement site 10:15

Masten Dam 10:00

Below Masten Dam measuring Tag #603 10:15

Figure 5-12. River Stage Conditions at Transect 2 on 8/13/04 with 89 cfs Flow at Lainhart Dam.

Transect 2

121 cfs 8/12/04 10:30 AM

– Ebbing Side of Controlled Release from G-92

Below Masten Dam Tag #603 10:30

Masten Dam 10:35

Above Masten Dam Tag #606 10:40

Figure 5-13. River Stage Conditions at Transect 2 on 8/12/04 with 121 cfs Flow at Lainhart Dam.

Transect 2

235 cfs 9/10/04 12:23 PM

Below Masten Dam Tag #603 12:23

Masten Dam 11:56

Above Masten Dam Tag #606 12:00

Figure 5-14. River Stage Conditions at Transect 2 on 9/10/04 with 235 cfs Flow at Lainhart Dam.

Transect 2

325 cfs 9/23/04 10:02 AM

Above Masten Dam Tag #606 10:03

Above Masten Dam Upstream of Tag #606 10:04

Masten Dam 10:07

Figure 5-15. River Stage Conditions at Transect 2 on 9/23/04 with 325 cfs Flow at Lainhart Dam.

Figure 5-16. River Stage Conditions at Transect 2 on 9/29/04 with 470 cfs Flow at Lainhart Dam.

Figures 5-17 and **5-18** are cross-sectional profiles of the upstream and downstream segments of the transect. The profiles depict the depth and lateral extent of floodplain inundation over the range of flows on those dates that water surface elevations were observed and measured.

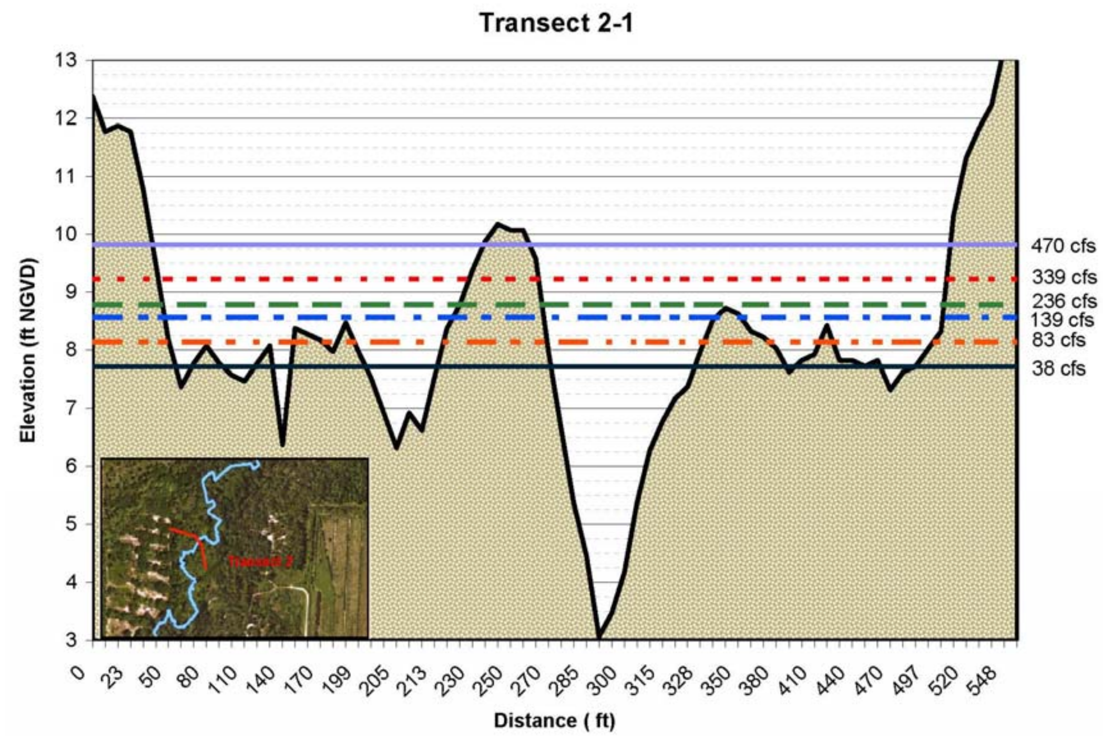


Figure 5-17. Transect 2-1 (RM 13.57) Cross Section and Observed Inundation Depth and Extent.

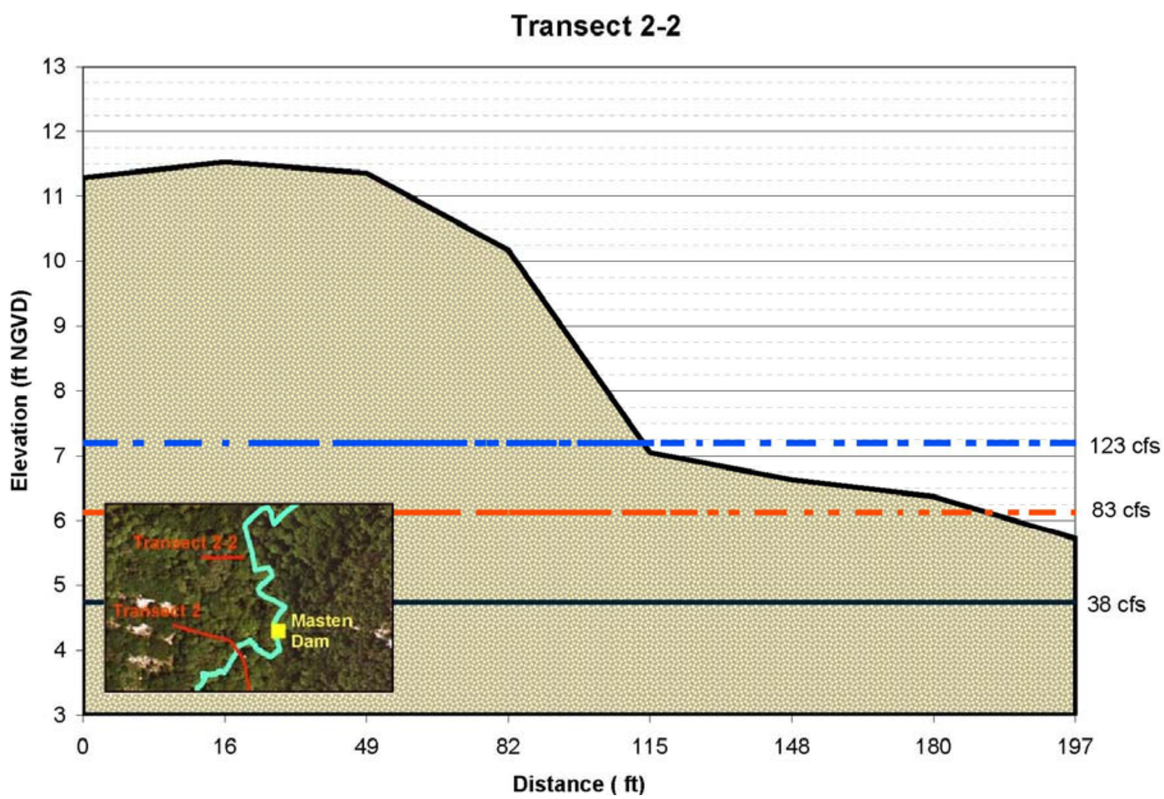


Figure 5-18. Transect 2-2 (RM 13.43) Cross Section and Observed Inundation Depth and Extent.

TRANSECT 3 (RM 12.07)

Figures 5-19 and **5-20** contain photographs of the river and floodplain at Transect 3 taken over a range of flows from 81 cfs to 258 cfs.

Transect 3

83 cfs 8/17/04 9:20 AM
91 cfs 8/13/04 11:20 AM

- Channel Flowing Within Banks
- Little to No Flow in Braided Streams

Flow within the channel: 8/17/04 9:33

Braided Channel at 35m North 8/13/04 11:54

Stream Flow Measurement Site 8/13/04 11:33

Figure 5-19. River Stage Conditions of Transect 3 on 8/13/04 and 8/17/04 with 83 cfs and 91 cfs Flow at Lainhart Dam.

Transect 3

On Transect at 15m Looking West Towards River 9/14/04 11:45

Stream Flow Measurement Site 9/14/04 12:05

Looking South at 35m North on Flowing Braided Channel 9/10/04 2:29

Edge of Floodplain 9/10/04 2:45

Figure 5-20. River Stage Conditions at Transect 3 on 9/14/04 and 9/10/04 with 182 cfs and 229 cfs Flow at Lainhart Dam.

Figure 5-21 is a cross-sectional profile of Transect 3. The profiles depict the depth and lateral extent of floodplain inundation over the range of flows on those dates that water surface elevations were observed and measured.

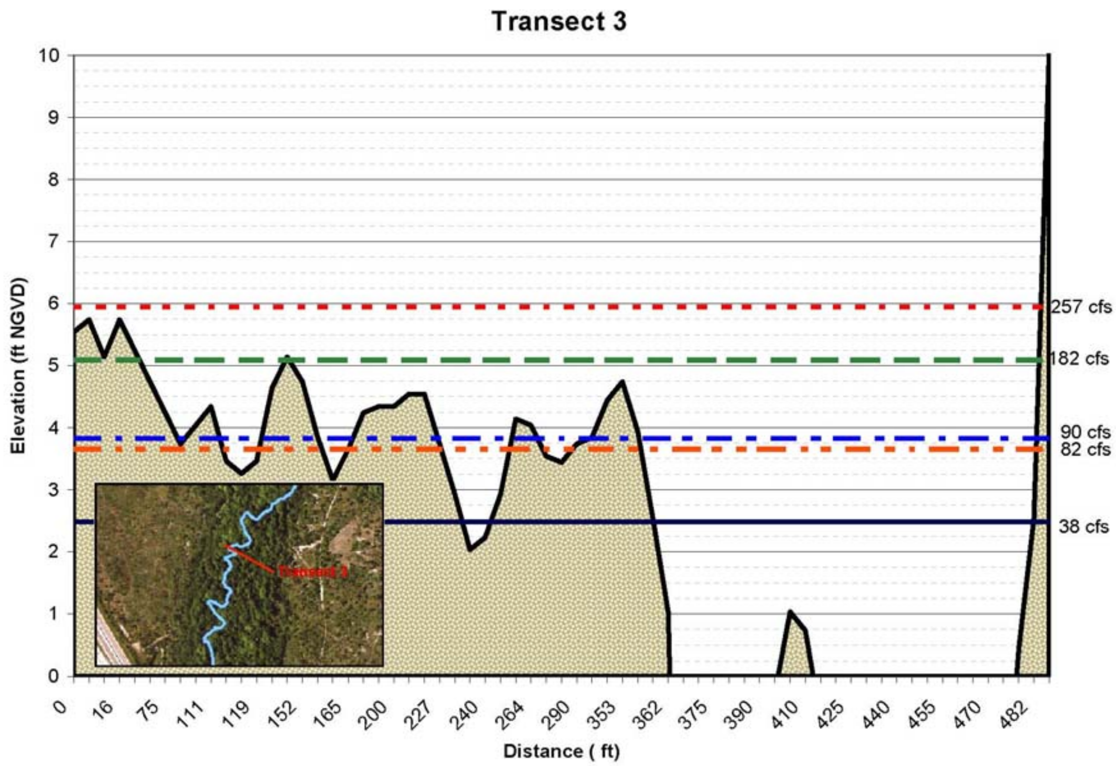


Figure 5-21. Transect 3 (RM 12.07) Cross Section and Observed Inundation Depth and Extent.

Flows of up to 88 cfs remained confined to the main river channel and braided lateral channels. The water stage elevation associated with that flow is just slightly below that of the riverine floodplain ground elevation. It is apparent that flows in excess of this amount would likely result in some degree of floodplain inundation.

TRANSECT 4 (RM 11.18)

Figures 5-22 through **5-25** are photographs of the river and floodplain at Transect 4 taken over a range of flows from 83 cfs to 461 cfs.

Transect 4

- 83 cfs 8/17/04 3:30 PM
- 93 cfs 8/13/04 12:49 PM
  - No Flow Outside of Channel

Stage Measurement Site Tag #608 8/13/04 12:56

Stream Flow Measurement Site 8/17/04 3:42

Double Logs in Channel 8/13/04 1:00

Figure 5-22. River Stage Conditions at Transect 4 on 8/13/04 and 8/17/04 with 83 cfs and 93 cfs Flow at Lainhart Dam.

Transect 4

- 186 cfs 9/14/04 1:25 PM
  - Knee Deep
  - Dry Hammocks

Stage Measurement Site Tag #608 1:26

Site of Double Logs in Channel 1:34

Figure 5-23. River Stage Conditions at Transect 4 on 9/14/04 with 186 cfs Flow at Lainhart Dam.

Transect 4

- 309 cfs 9/23/04 11:36 AM
  - Visual Flow Through Entire Floodplain
  - Waist Deep
  - Causeway Still Dry


At 25m South Looking Towards Floodplain 11:20


Edge of Floodplain 11:05


Stage Measurement Site Tag #608 11:40

Figure 5-24. River Stage Conditions of Transect 4 at 9/23/04 with 309 cfs Flow at Lainhart Dam.

Transect 4

- 461 cfs 9/29/04 12:30 PM
  - Visual Flow Through Entire Floodplain
  - Over Waist Deep
  - Water Hickory at 85m 20" Deep


Edge of Floodplain Looking North 1:05


Water Hickory 12:51


Stage Measurement Site Tag #608 12:32

Figure 5-25. River Stage Conditions at Transect 4 on 9/29/04 with 461 cfs Flow at Lainhart Dam.

Figure 5-26 is a cross-sectional profile of the transect. It depicts the depth and lateral extent of floodplain inundation observed over the range of flows observed during the course of this floodplain evaluation.

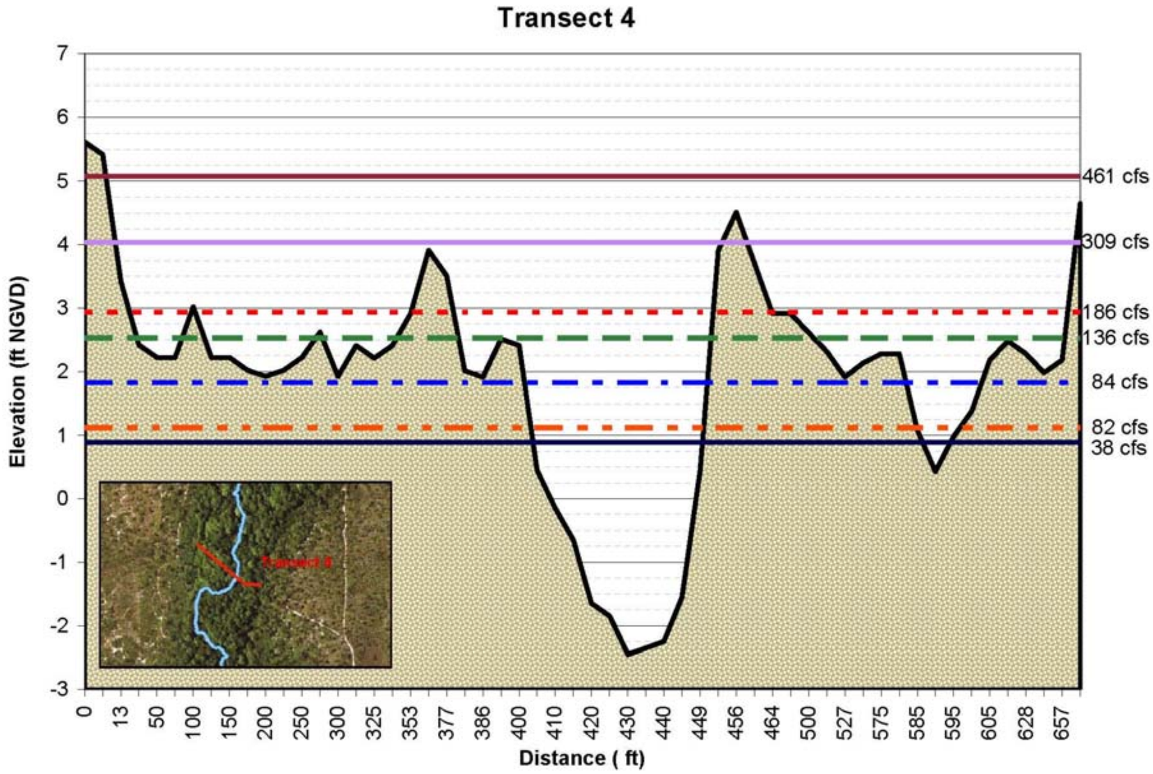


Figure 5-26. Transect 4 (RM 11.18) Cross Section and Observed Inundation Depth and Extent.

Of the four transects, Transect 4 (RM 11.18) is the farthest downstream and the water stage elevations are impacted by daily tidal regimens. The difference in stage at a flow of between 82 cfs and 84 cfs clearly depicts the degree of tidal influence on the particular date that these measurements were made. While not directly impacted by the saline waters coming upstream from Jupiter Inlet, the water surface at this location is obviously raised as the Lainhart Dam flow meets the incoming tidal prism from the downstream ocean. No floodplain inundation was observed nor is any inundation expected at the river stages associated with the 84 cfs flow at either low tide or high tide.

GENERAL OBSERVATIONS AND CONCLUSIONS

The floodplain inundation observed at the four transects during the episodic field study is, in general, consistent with the conclusions of the controlled release study. Measured river stages at the four transects were plotted against flow at Lainhart Dam in **Figure 5-27**. In general, at all four transects flows of 90 cfs or less seem to result in little or no overbanking of the main river channel or flooding of the floodplain. Conversely, flows of 110 cfs or greater would appear to begin flooding at least some of the floodplain areas.

The stage/flow relationship at Transect 2 (RM 13.43) is distorted to a somewhat flatter relationship on the upstream side of Masten Dam at low flows and a steeper relationship on the downstream side. The impacts of Masten Dam seem to dissipate by the time the flow reaches Transect 3 at RM 12.07. Tidal fluctuation has imperceptible impacts at Transect 2 (downstream section). Tidal fluctuation had an insignificant impact at Transect 3 during the 8/17 Controlled Release Study. Tidal fluctuation appears to have a regular and noticeable impact on water stages at Transect 4. Also note that observation points made after Hurricane Jeanne (see **Figure 5-3**; end of September 2004) were not included in the stage/flow figure (**Figure 5-27**). Post hurricane investigations indicated that the storm damage resulted in fallen branches and snags in the channel which may change the channel conveyance capacity. A periodic re-evaluation of the flow-stage relationship is needed for adaptive management.

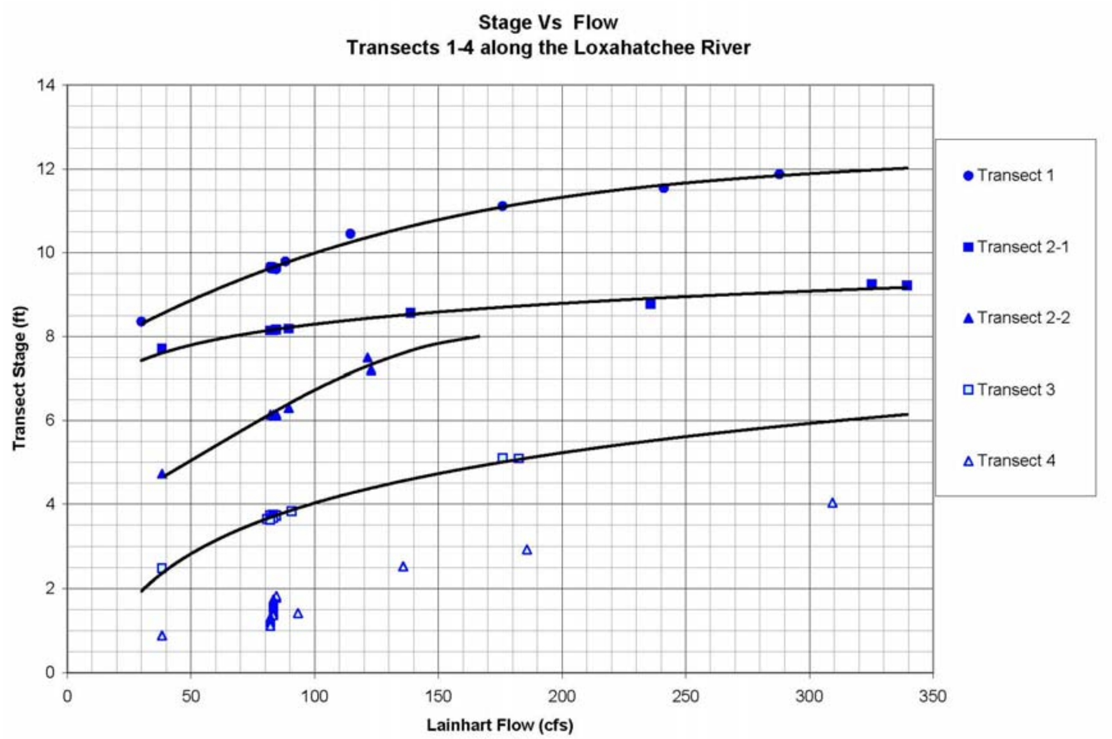


Figure 5-27. Observed Surface Water Stages at Various Flow Rates Over Lainhart Dam.

The basic assumption underpinning the strategy and approach for performing this evaluation is that by achieving hydrologic performance measures for "Floodplain Swamps" and "Hydric Hammocks," hydrologic requirements for the entire floodplain ecosystem will be met and achieved. In **Chapter 4**, the hydroperiod requirement for a healthy floodplain swamp vegetative community in the Northwest Fork is for inundation to occur during the wet season (June through November) for 4 months to 8 months in a year. The hydrologic requirement for hydric hammocks is for the community to be inundated by major storm events for about 2 to 6 inches above the ground surface. The total number of inundation days during a year can range from less than 30 days to about 60 days, depending on the elevation of the hydric hammock community. However, the inundations do not have to be continuous. A schematic hydroperiod diagram is presented in **Figure 5-28** which shows the range of surface or groundwater stage necessary to achieve a healthy cypress swamp and hydric hammock community. The stage is expressed as relative to the mean ground elevation of cypress swamps. The two lines in the schematic diagram are the maximum and minimum average monthly water surface elevations. With appropriate management, this range of water stage elevations could be maintained during an average year. As can be seen, the inundation of the floodplain would typically occur in the wet season. However, due to the variations of rainfall from year to year, La Niña and El Niño effects can shift monthly rainfall values significantly from the average monthly rainfall for any given month. Thus, in some years, a good portion of the 4- to 8-month inundation period may occur in the dry season. Furthermore, daily fluctuations, which are not illustrated in **Figure 5-28**, may also push the stage out of the range indicated in the figure, particularly during extreme events like hurricanes.

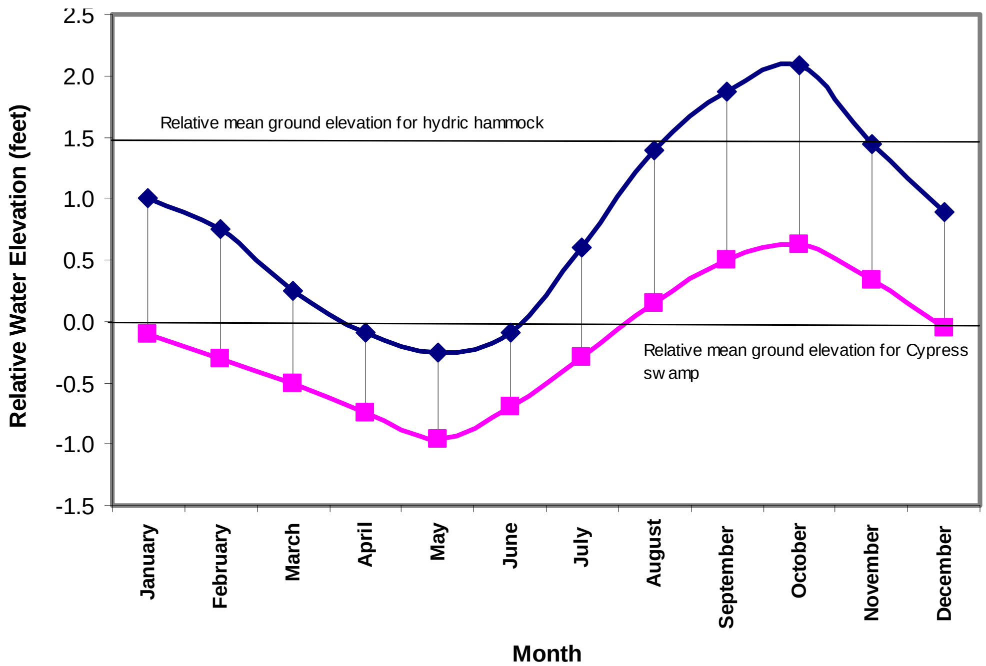


Figure 5-28. Schematic Annual Hydroperiod Diagram for Cypress Swamps and Hydric Hammocks in the Northwest Fork of the Loxahatchee River.

In the riverine floodplain, hydric hammock communities are generally distributed on or below the periphery of the floodplain with a mean ground elevation about 1.5 feet higher that that of cypress swamp (**Figure 5-28)**. This is consistent with our field measurements taken during the flow/stage and WRAP analyses. For example, in the area of Transect 1, the mean ground elevation of cypress swamp is at 9.9 feet (ranging from 9.3 to 10.2 feet) whereas the mean elevation for hydric hammocks is 11.5 feet (ranging from 11.0 to 12.2 feet). Using the flow stage relationship presented in **Figure 5-27**, the required flow over Lainhart Dam needs to be a minimum of 110 cfs to inundate the entire cypress swamp and to be from 200 cfs to 400 cfs to inundate the hydric hammock communities. Our field observations indicated that 400 cfs flows created stages inundating the upper boundary of the hydric hammock communities. Thus, flows at Lainhart Dam of 110 cfs to 400 cfs for 4 months during the wet season should be sufficient to provide the appropriate degree of wet season riverine floodplain inundation.

In the dry season when the floodplain does not need to be inundated (December to May), our measurements and observations indicate that flows over Lainhart Dam less than 90 cfs will not inundate the floodplain. From a water management perspective, normal dry season flow variability ranging from 50 cfs to 90 cfs is desirable for the riverine floodplain. Extended inundation of the riverine floodplain during the dry season is considered harmful since it would decrease seed germination and seedling survival of the desired floodplain community species.

CHAPTER 6

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Chapter 6

Modeling Freshwater Flows and Salinity in the Loxahatchee River and Estuary

INTRODUCTION

Estuaries are the most productive ecosystems on the earth and freshwater flows are the single most important determinant of estuary health. Alterations in the timing and amount of flows will influence the overall estuary productivity and health. In the Loxahatchee River, the importance of freshwater flows has been presented in the previous chapters. Salinity in the Northwest Fork of the Loxahatchee River and Estuary is controlled by both freshwater flows and tidal circulation, which represent the competition between river and ocean influences. The hydroperiods of the Loxahatchee River floodplain ecosystem also may be influenced by freshwater flows into the river. Formulation of the Preferred Restoration Scenario for the Northwest Fork of the Loxahatchee River and Estuary largely depends on developing models to accurately predict long-term freshwater flow and salinity in the Loxahatchee River and Estuary.

During the past several years, the South Florida Water Management District (SFWMD) has initiated several data collection and model development projects. To date, three models have been developed to simulate freshwater flows and salinity conditions in the Loxahatchee River and Estuary (**Figure 6-1**). These models include a watershed hydrologic model (WaSh) simulating long-term freshwater flows from all tributaries into the Northwest Fork, a two-dimensional (2-D) estuarine hydrodynamic and salinity model (RMA) that simulates the influence of the freshwater flows and tide on salinity conditions within the Loxahatchee River and Estuary, and a Long-term Salinity Management Model (LSMM) that predicts daily salinity conditions according to freshwater flows from the Loxahatchee River Watershed. The LSMM was developed based on the results from the RMA model. During the model development process, a 39-year period of record (POR) consisting of daily freshwater flows into the river was simulated with the WaSh model to ensure that a wide range of climatic conditions was included. Various flow scenarios were proposed and the resulting daily salinity at key salinity and ecological assessment sites was simulated with the LSMM. An integrated ecological assessment was conducted to evaluate the effects of the flow scenarios on the health of the Valued Ecosystem Components (VECs): freshwater floodplain vegetation, fish larvae, oysters and seagrasses. This assessment is critical in selecting restoration alternatives to achieve maximum benefits to all the VECs throughout the system. The purpose of this chapter is to document the calibration and validation results of these models and to describe how these models are used to evaluate the Northwest Fork Restoration Scenarios.

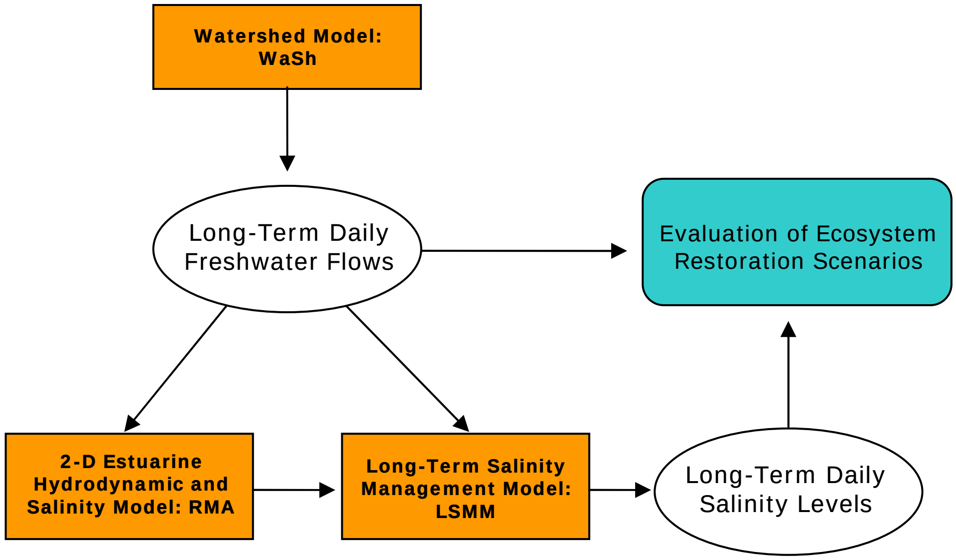

Figure 6-1. The Relationship of the Three Models Used to Evaluate Restoration Plan Scenarios for the Ecosystems in the Loxahatchee River Watershed.

Table 6-1 lists the time steps and the length of simulations for each model. Because ecological assessments require long simulation periods that are beyond the capability of a multiple dimensional hydrodynamic model, the Long-term Salinity Management Model (LSMM) was designed to provide a bridge between the hydrodynamic model (RMA) and the VEC models so they could interact in the same long-term simulation period.

Table 6-1. The Time Scale of the Freshwater Flow and Salinity Models.

Study Components/Models	Spatial Resolution	Time Step	Maximum Length of Simulation
Watershed Model (WaSh)	Site-specific data	Daily or monthly	Several years to several decades
Estuary Model (RMA)	Thousands of data points that may not coincide with specific sites	One minute to 30 minutes	Several months to several years
Ecosystem Evaluation Tools (LSMM and VEC)	Site-specific data	Daily, monthly, or annual	Long-term (several decades)

MODELING FRESHWATER FLOWS

THE WATERSHED (WASH) MODEL DESCRIPTION

Freshwater flows from major tributaries of the Northwest Fork of Loxahatchee River and Estuary are simulated with the watershed (WaSh) model. This model was developed based on restructuring the HSPF (Hydrologic Simulation Program – Fortran; Donigian et al. 1984) into a cell-based system with the addition of a groundwater model and a full dynamic channel routing model (Wan et al. 2003). The WaSh model is capable of simulating hydrology in watersheds with high groundwater tables and dense drainage canal networks, which is typical in South Florida. The model consists of four basic components: (1) a cell-based representation of the watershed basin land surface, (2) a groundwater component that is consistent with the basin cell structure, (3) a surface water drainage system, and (4) water management practices. Key features of the model are surface water and groundwater interactions, irrigation demands, and transfers between elements of the surface water drainage network. For each cell, the model uses an infiltration routine to determine the amount of rainfall that infiltrates into the groundwater, evaporates into the atmosphere, or drains to the surface water system. The HSPF (Version 12) modules PWATER and IWATER are used for this portion of the model. The infiltrated water is routed to a groundwater model that represents the unconfined aquifer in the watershed. The groundwater model receives the infiltrated water, exchanges groundwater between cells, and also exchanges water between surface water flow and groundwater flow. The surface water drainage system consists of a cell-based system and a reach-based system. The reach-based system is typically configured to follow the major canals, streams, and rivers and supports branches and common flow structures. The water quality component of WaSh is built on the surface water, groundwater, and channel flow components of the model. The application of the WaSh model in the Loxahatchee River Watershed focuses on hydrologic simulation. The WaSh model is supported by a Graphic User Interface (GUI) that was developed as an ArcView extension. The GUI handles file management, model configuration, execution, and post processing. The WaSh model also supports numerous water management practices such as irrigation, reservoirs, Stormwater Treatment Areas (STAs) and land use changes. Key components of the WaSh model are summarized in **Table 6-2**.

Table 6-2. The Watershed (WaSh) Model Components and Functions.

Model Component	Modeling Approach	Functions
Surface Water Flow	PWATER and IWATER of HSPF with PQUAL, SEDMNT, IQUAL, and SOLIDS for water quality	High water table algorithms of HSPF
Groundwater Flow	A new 2-D unconfined groundwater flow model with a prescribed leaching function for water quality constituents	Canal drainage and recharge
Channel Flow	A new 1-D fully dynamic shallow wave model with a scalar mass transport function for water quality	Structures, branching, point sources
Water Management	Reservoirs, Stormwater Treatment Areas, irrigation supply and demands, land use changes	Executed by an ArcView GUI

Model Cell Structure and Cell-based Routing

The WaSh model uses a uniform structured grid network. Each cell represents a discrete part of the model domain and has associated physical characteristics such as land use, soil type, ground elevation, impervious area, and a representative ground slope. Hydrological parameters relating runoff, infiltration, and evaporation are specific to these attributes, particularly land use types. If tertiary canals are present in the cell, then the length and width of canals in the cell are computed and added as a cell attribute. Generally, the cell attributes are obtained by combining the cell network with Geographic Information System (GIS) coverage for each of the physical characteristics. For the purpose of routing the simulated daily runoff from each cell, a special cell attribute is assigned to indicate where runoff from that cell is directed. Each cell is labeled as one of three primary types: (1) free cell, (2) canal cell, or (3) reach cell. A free cell represents an area of the basin that does not contain canals. Canal cells are any cells with tertiary canals that are not coincident with the reaches. Reach cells are cells that contain a reach (major canals) in the primary canal system. Some secondary canals can be included in the reach system. These labels are needed to designate the types of surface water and groundwater interactions that may occur for a given cell. **Table 6-3** lists the methods in which water is routed for each type of cell.

Table 6-3. WaSh Water Routing Operations for Each Cell Type.

Cell Type	Flow Routing Operations
Free	Infiltration is directed to cell groundwater Surface water is directed to a nearby cell's canals
Canal	Infiltration is directed to cell groundwater Surface water is directed to cell canals Groundwater can be exchanged with canal surface water Surface water can be exchanged between the canal and the reach
Reach	Infiltration is directed to cell groundwater Surface water is directed to the cell's reach or nearby cell's canals Groundwater can be exchanged with canal or reach surface water Reach water can be exchanged with canal water

Surface Water and Groundwater Interaction

The surface water and groundwater is modeled in the same grid network. For each cell, WaSh uses the PWATER and IWATER modules of HSPF (Version 12) to simulate surface water hydrology (**Table 6-2**). A detailed description of these modules is available in the HSPF user's manual (Donigian et al. 1984). Version 12 includes recent model enhancements that simulate irrigation demand, high water tables, and wetland conditions that are common in South Florida (Aqua Terra 1996, 1998). The HSPF routine is implemented in one-hour time step for 24-hour blocks. Thus, the HSPF-based routine is applied daily for each cell and water balance, consisting of rainfall, evaporation, soil storage, surface runoff, and infiltration to groundwater. At the end of each one-day simulation period, the accumulated surface runoff and infiltration are routed to the drainage and groundwater systems, respectively. All HSPF model parameters are calibrated and assigned to each cell based on the land use and soil type characteristics as additional cell attributes.

The groundwater module in WaSh is based on the numerical solution of the standard groundwater flow equation for an unconfined aquifer. The model operates on a daily time step, during which it receives infiltrated water, loses water to evaporation, and exchanges water with adjacent cells and with canals. The basic governing equation for the groundwater module is:

$$\rho \frac{\partial h}{\partial t} = \frac{\partial}{\partial x} K_x (h - h_c) \frac{\partial h}{\partial x} + \frac{\partial}{\partial y} K_y (h - h_c) \frac{\partial h}{\partial y} + S_i - S_e + S_c + S_r \qquad [1]$$

where h is the groundwater elevation, ρ is the porosity, K_x and K_y are the hydraulic conductivity in the x-, and y- directions, h_c is the aquifer base elevation, and S_i, S_e, S_c, and S_r are source/sink terms representing infiltration, evaporation, exchanges with the canal cells, and exchanges with reaches. The governing equation is solved numerically using the basin cell structure. A second-order finite difference approximation is used for the second derivatives, and an explicit backward difference approximation is used for the time derivative. During each time step the right-hand side of the equation is evaluated based on current time level conditions, and the new water elevation is found. By designating the equation parameters and water elevation h for each cell by the indexes $_{i,j}$, and the time level by the index ^{m}, the resulting finite difference equation for each cell is:

$$\frac{1}{\rho_{i,j}}\frac{h_{i,j}^{m+1}-h_{i,j}^{m}}{\Delta t}=K_x\left[\frac{(\frac{h_{i,j}^m+h_{i+1,j}^m}{2}-h_c)}{\Delta x}\left(\frac{h_{i+1,j}^m-h_{i,j}^m}{\Delta x}\right)-\frac{(\frac{h_{i,j}^m+h_{i-1,j}^m}{2}-h_c)}{\Delta x}\left(\frac{h_{i,j}^m-h_{i-1,j}^m}{\Delta x}\right)\right]+$$
$$Ky\left[\frac{(\frac{h_{i,j}^m+h_{i,j+1}^m}{2}-h_c)}{\Delta y}\left(\frac{h_{i,j+1}^m-h_{i,j}^m}{\Delta y}\right)-\frac{(\frac{h_{i,j}^m+h_{i,j-1}^m}{2}-h_c)}{\Delta y}\left(\frac{h_{i,j}^m-h_{i,j-1}^m}{\Delta y}\right)\right]+S_{i_{i,j}}^m-S_{e_{i,j}}^m+S_{c_{i,j}}^m+S_{r_{i,j}}^m \qquad [2]$$

where Δt is the time step (one day), and Δx and Δy are the grid cell dimensions in each direction. During each time step the right-hand side of the equation is evaluated based on current time level conditions, and the new water elevation is found by solving for $h_{i,j}^{m+1}$. When an active cell is adjacent to the grid boundary or to an inactive cell, a no-flow condition is imposed.

Implementation of the groundwater model has required some modification to the PWATER module, primarily to account for evaporation from groundwater and also to link to the irrigation and high water table modules. The original HSPF groundwater algorithm is based on groundwater storage, AGWS. Changes to the storage for each time step are due to infiltration (GWI), evaporation (BASET), and flow to surface water (AGWO). Infiltration is predicted using subroutines representing the Stanford Watershed Model approach. Evaporation is modeled as a loss term, which is based on a model parameter BASETP. The discharge is based on a rating curve, specified by the model parameters AGWRC and KVARY. This groundwater discharge algorithm in HSPF has been disabled and replaced by the equivalent parameters in WaSh. For each of the cells, two of the source terms on the right-hand side of the equation, $S_{i_{i,j}}^m$ and $S_{e_{i,j}}^m$ are set equal to output variables from HSPF PWATER groundwater subroutine related to infiltration (GWI) and evaporation (BASET). The groundwater elevation $h_{i,j}$ replaces the storage variable, AGWS, and when combined with the two source terms, represent essentially the same processes as AGWO in HSPF. However, this modification provides a process-based approach to represent surface water and groundwater interactions when compared with the rating curve-based groundwater discharge approach in HSPF. For example, the source/sink terms for a canal/reach cell are now defined as:

$$S_{c_{i,j}}^m=\frac{\Delta H\, C_c}{A} \qquad [3]$$

$$S_{r_{i,j}}^m=\frac{\Delta H\, C_r}{A} \qquad [4]$$

where ΔH is the difference in groundwater elevation and canal or reach surface water elevation, which are dynamically tracked in WaSh, A is the cell area, and C_c and C_r are the conductance of canal or reach, respectively. The conductance is physically related to the hydraulic conductivity of the stream bed material and the length and width of the canal. In the Loxahatchee River watershed, the hydraulic conductivity of the deep canals (reaches) and shallow canals is different.

The hydraulic conductivity and canal dimension are provided as input data for each cell according to the basin hydrography and land use.

Irrigation Demand and High Water Table Conditions

The WaSh groundwater module also has been developed to interact with the irrigation module and the high water table module of the HSPF. WaSh simulates the irrigation demand by monitoring the moisture in the upper and lower soil zones and generating a demand for water based on the existing moisture relative to the desired moisture level that is specified by the user. After the irrigation demand is calculated, the algorithm tries to meet the demand by supplying water from a number of sources. Groundwater can serve as both an irrigation source and an irrigation sink (receptor) in the HSPF irrigation algorithm. In each case, the amount of water demanded from, or applied to, the groundwater is extracted or added to the cell's groundwater volume. At the beginning of each day, the irrigation demand is calculated and if groundwater is affected, then the groundwater elevation $h_{i,j}$ is adjusted according to the following equation:

$$h_{i,\,j} = h_{i,\,j} + \Delta V / \rho \qquad [5]$$

where ΔV is the volume (expressed as depth) of groundwater irrigation demand or application for the cell calculated by the HSPF irrigation module, and ρ is the aquifer porosity as defined previously in Equation [1].

The high water table module in the HSPF requires certain vertically referenced parameters and variables to allow for exchange of water between storage components when the groundwater level interferes with the upper and lower zone storage (UZS and LZS). For applications in WaSh, the vertical referencing is already completed, as the surface elevation (a cell attribute) and the groundwater elevation h are all referenced to the same datum. Thus, the only required modification is to provide these two variables to the high water table algorithms. The HSPF high water table algorithm then calculates the exchange between the storage zones and the groundwater. The groundwater elevation is updated with Equation [5], where ΔV now represents the exchange between the upper and lower storage zones.

Drainage Canal Network and Canal Routing

The surface water drainage canal network is modeled implicitly in the cell-based system and explicitly in the reach-based system. The major channels are simulated in the reach-based system which consists of a series of reaches and nodes. This drainage system is separated from the cell system, but its elements (reaches and nodes) overlay the cell network and coincide with a subset of the cells. This system is typically configured to follow the major canals, streams, and rivers in the basin. The small or tertiary canals are represented in the cell-based system. These canals receive surface and subsurface runoff from the adjacent cells and exchange water with neighboring canal cells.

Flow through the reach-based systems is modeled using the continuity equation, Equation [6], and the depth- and width-averaged shallow water wave equation, Equation [7]. The governing equations are:

$$\frac{\partial wh}{\partial t} = \frac{\partial q}{\partial s} + Q_e \qquad [6]$$

$$\frac{\partial q}{\partial t} + \frac{\partial uq}{\partial s} + \frac{gw}{2}\frac{\partial h^2}{\partial s} = -w\,\tau_b - gwh\,\frac{\partial \eta}{\partial s} \qquad [7]$$

where q is the flow, u is the width- and depth-average flow velocity, g is the acceleration due to gravity, w is the canal width, h is the water depth (referenced to the canal bed), η is the bed elevation, t is time, and s is distance along the canal. The bottom stress τ_b is based on a Manning's n formulation. Boundary conditions can be one of two types: a specified flow or a specified water elevation. Specified flow conditions are typically used when a flow structure controls the flow out of the system. The water elevation (or head) condition is used when the system drains unobstructed into a receiving water body. The governing equations are solved using a finite volume procedure, with the reach and node system for a single branch equivalent to a finite volume staggered grid approach.

The source term Q_e in the continuity equation, Equation [6], consists of point sources or sinks, exchange with groundwater, and exchange with canals from the cell-based system. The units for the source term are flow per unit length of channel. The general form for the source term can be expressed as:

$$Q_e = Q_{kp} + Q_{ki} + Q_{r,gw} \qquad [8]$$

where Q_{kp} are external sources or sinks (user-specified time series), $Q_{r,gw}$ is the exchange with the groundwater and is equal to S_r, the exchange calculated in the groundwater model, Equation [1], and Q_{ki} is the exchange with the canal cells where the tertiary canals are connected with the reach.

When the reach-based system contains branches, the flow in each branch is determined independently. The method for estimating the flow between branches depends on whether the flow is natural at the connection or whether a structure exists. When a structure is present at the branch connections, the flow is determined using a rating curve specific to the structure. Since the flow can be bi-directional, the flow direction for the time step is first determined from the water elevations in the reaches at the branch juncture. The water elevations for headwater and tailwater are then assigned appropriately and the rating curve is used to calculate the flow. It is noted that structures can also occur at any node along the reach node system. When a structure is present, the flow at that node is determined at the beginning of the time step using the structure flow formulas and its value replaces the momentum equation for that node. When no structures are present at the branch connections, the flow is solved using the shallow water wave equation, Equation [7], and the continuity equation, Equation [6]. The two equations are solved explicitly for the flow between branches using the two reaches that connect the branches. The calculated flow in the 'local' explicit solution is then used as a boundary condition for the implicit solution for the upstream branch and as a source to the downstream reach.

Flow in the cell-based canal system (i.e., the tertiary canals) is represented in the WaSh model using the same governing equations and numerical scheme as used for the reach-based system. To implement this approach, the cell-based canal parameters are first mapped into a 'local' branch and reach network. When this mapping is completed, the solution algorithm for the reach system can be applied to the local system with only minor modifications to the downstream boundary condition and the source terms. The source term in the cell canal would then include surface runoff simulated with HSPF routines.

The tertiary canals are characterized by the total length *LC* of these canals within the cell, the average canal width w_c, the average canal bottom elevation, and a critical or 'design' water depth. These parameters are attributes of the cell. They can be obtained by mapping GIS hydrologic data onto the basin grid and then specifying widths, bottom elevations, and critical depths based on the cell land use. The surface water elevation is the dependent variable in the system. In order to map these parameters into a branched network, each cell's canals are designated as a single reach. The reach parameters for the cell are determined as follows:

If the total canal length *L* is less than the cell length *LC*, then:

$$\Delta s = L, \quad and \;\; w = w_c \qquad [9]$$

If the total canal length *L* is greater than the cell length *LC*, then:

$$\Delta s = LC, \quad and \;\; w = w_c * \frac{L}{LC} \qquad [10]$$

After the cell-based canal parameters are transformed into reach parameters, the connectivity of the branch network is determined. The connectivity of the cells is used directly to establish branches and the assignments of reaches within each branch. The canal-to-canal flow is generally towards the reaches, but the instantaneous flow is determined by the difference in relative surface water elevations between hydraulically connected canal cells. When canal cells exist in cells with reaches, the canals are assumed to be hydraulically connected to the reach via a structure. It is in these cells that water can flow between the canals and reaches. Between the reaches and tertiary canals, the flow is assumed to be controlled by pumps. The pumping capacity is derived from land use types, representing the design (or estimated) drainage capacities for the canal systems associated with each land use. The drainage capacities of the major land use types are the key parameters for calibrating the magnitude of peak flow during a high magnitude and low frequency event.

IMPLEMENTING THE WaSh MODEL

Model Setup

Delineation of the Loxahatchee River Watershed is described in detail in **Chapter 2**. The WaSh model was implemented into four regions of the Loxahatchee River Watershed (**Figure 6-2**). These regions include all of the major drainage basins except the Coastal Basin. The JDSP region (A) includes the North Fork, Kitch Gauge, Park River, and the Loxahatchee Estuary basins. The Pal-Mar and Grove region (B) includes the Pal-Mar, Historic Cypress Creek, Grove West, and Grove East basins. The Jupiter Farms region (C) includes the Jupiter Farms and the Wild and Scenic basins. The C-18 region (D) represents the C-18/Corbett Basin and flow diversion from the L-8/Grassy Basin. The cells for each of the regions are shown in **Figure 6-2.**

The cell size was 750 ft by 750 ft for the Jupiter Farms region, 1000 ft by 1000 ft for the JDSP region and Pal-Mal/Grove region, and 1500 ft by 1500 ft for the C-18 region.

Input data required to generate the model grid include primary and secondary basin coverages, polygon features with basin name attributes, hydrography including streams and canals as line or polyline features, the 2000 base land use coverage, soil coverage, and land surface elevation. The land surface contour was resampled (100-foot intervals) based on 5 ft by 5 ft Light Detection and Ranging (LIDAR) data to get a smooth land surface profile and to remove data artifacts. For limited areas where LIDAR data are not available, the 1-foot contour was used. Using the ArcView GUI, these coverages are overlaid to get an aerial extent of the model domain along with cell attributes of land use type, soil, canal length and width, and elevation.

When creating the primary reaches for the basins, the hydrography theme is overlaid on the grid and those grid cells intersecting with polylines of the hydrography theme are classified as canal cells. The canal length in a grid cell is calculated with all the intersecting canal segments inside a grid cell. Reach cells are created by digitizing major river segments and canals starting from the basin outlet. After digitizing, the length of a reach, which is typically the grid cell size, is specified to allow for redistribution of the nodes along the reach network. Each of the reach segments has a reach ID along with the width and bottom elevation assigned according to the cross-section of the major canal and river segment. In **Figure 6-2**, the cells are color coded to represent free cells (turquoise), canal cells (green) and reach cells (pink). The surface elevation of cells is used to create flow paths. In general, flow in free cells is routed to the nearest canal or reach cell (**Figure 6-2**, Region B). A no flow boundary condition is imposed along the boundary cells.

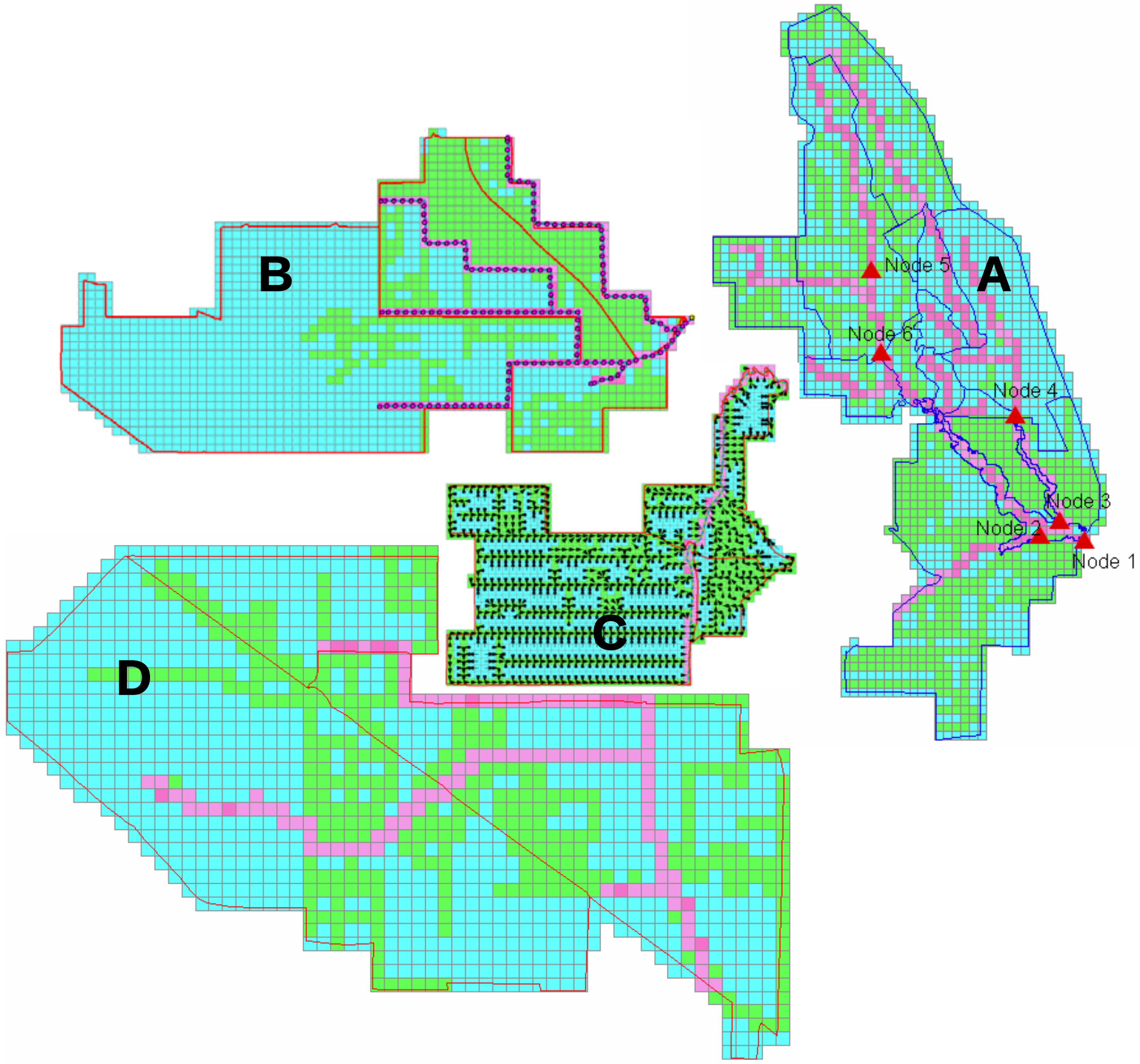

Figure 6-2. The Loxahatchee WaSh Model Grids: (A) JDSP Model, (B) Pal-Mar-Grove Model, (C) Jupiter Farms Model, and (D) C-18 Model.

Note: Free cells, canal cells, and reach cells are color coded turquoise, green, and pink, respectively. In Region A, the thin blue line represents the model boundary, and the nodes represent examples of possible model output locations. In Region B, the nodes are shown in the reach system. In Region C, flow routing directions are shown with arrows.

Each of the cells is linked with a Master Lookup Database consisting of HSPF parameters, evapotranspiration (ET) coefficients, canal parameters, and aquifer properties. Based on the grid cell attribute, this master database is queried to populate the respective parameters for each cell in the grid. Some of the model parameters can be changed during the model calibration process.

The other important input data required by the model are rainfall and ET. These data were obtained from the District's South Florida Water Management Model (SFWMM) for the period from 1965 to 2000. The dataset was extended to March 2004 with available rainfall and ET data stored in the District's DBHYDRO database in the model area. Daily rainfall is disaggregated into hourly rainfall based on an analysis of available hourly rainfall distribution in South Florida.

Model Calibration and Validation

The Loxahatchee WaSh model has been calibrated with five flow monitoring stations (**Figure 6-3**). Flow data collected at the G-92 Structure were not used since it was determined that the data are likely not accurate. The Kitching Creek station started to collect data in the early 1980s. The data are not continuous until 1990, and thus only the data collected after 1990 are used for calibration and validation of the JDSP model. The Hobe Grove and the Cypress Creek stations have been collecting data since 1980; however, there are significant periods of time when data were not collected or are missing. Data collected from the flow stations at S-46 and Lainhart Dam have the longest record. Only the data collected after 1987 were used for WaSh model calibration and validation due to structure changes of G-92. All the collected flow data were evaluated for their validity before being used for model calibration and validation. In addition, water level data collected in two groundwater wells (PB-689 and M-1234) were used. PB-689 is located in the C-18/Corbett basin where the land use is dominated by wetland whereas M-1234 is located in a forested area of the Cypress Creek basin.

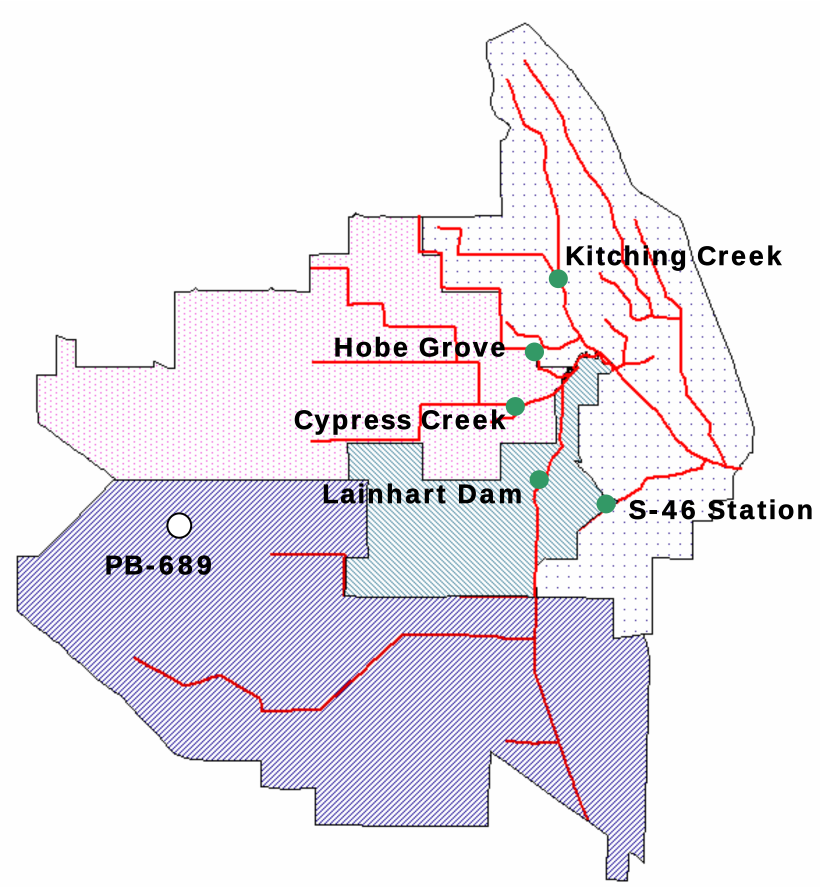

Figure 6-3. Flow Monitoring Stations (green dots) and Groundwater Monitoring Stations (white dots) in the Loxahatchee River Watershed for WaSh Model Calibration.

Model calibration involves conducting a model simulation of each region for the period of record (POR) and comparing the simulated flow with the observed flow. The model parameters are then adjusted in subsequent simulations to improve the shape of simulated flow time-series until the model output meets the performance criteria. In general, the hydrological calibration is conducted in two main steps:

1. Macro Scale: Adjust hydrological parameters to obtain the long-term basin water budget.
2. Micro Scale: Fine tune model parameters to get the best match between observed and simulated flow. At this stage, the shape of the hydrograph is adjusted with respect to peak and base flow. Groundwater levels were also checked with data from observation wells.

In the first step, the long-term water budget is used to ensure that the model calibrations are not biased for one type of climatic condition. Another component of the water budget calibration is verifying that the fractions of groundwater and surface water contribution to runoff properly reflect the partitioning between surface runoff and subsurface runoff. For this component of the simulation, the average annual water budget for each of the land uses as well as for the entire watershed were used to make decisions to adjust parameters. An initial run of the model was made using model parameters that were calibrated in the St. Lucie Estuary Watershed (Wan et al. 2003). The most sensitive model parameters in completing the water budget calibrations are evaporation coefficients for individual months and infiltration parameters of the HSPF. An example of the water budget is provided in **Table 6-4** for the Pal-Mar and Grove regions. The water budget is partitioned into the Pal-Mar and historic Cypress Creek basins, which consist mostly of wetland and forest, and the Grove West and Grove East basins, which consist mostly of irrigated citrus groves. Citrus irrigation significantly increases the runoff from a water budget perspective.

Table 6-4. Average Annual Water Budget (inches) for the Pal-Mar and Grove Regions.

Basins	Rainfall	Irrigation	ET	Runoff		Storage
				Surface	Subsurface	
Pal-Mar & Historic Cypress Creek	61.2	--	44.9	13.6	2.6	1.7
Grove West & Grove East	61.2	8.2	40.2	16.9	11.9	0.2

After the long-term calibration is completed, the next step is to validate the model by matching the simulated daily flow hydrograph to the measured daily flow values recorded for each of the flow stations. The more significant parameters to be calibrated during this step includes the groundwater cell conductance parameters that control the rate at which groundwater flows to the canals, the irrigation parameters, and the canal pumping parameters that control the rate at which tertiary canals flow to primary reaches. To a lesser degree, the length-scale parameter associated with surface drainage (LSUR) has an effect on the shape of the hydrographs. Reducing the LSUR increases runoff and decreases infiltration. The model validation process is similar to the calibration process, except that a different POR is used for the relevant input data. The model parameters are kept constant. Model validation is considered complete if the simulation meets the performance criteria. Otherwise, the model is recalibrated and validated.

Model calibration and validation performance are evaluated with two of three criteria recommended by the ASCE Task Committee on Definition of Criteria for Evaluation of Watershed Models (1993): the deviation of volume, the Nash-Sutcliffe coefficient, and the coefficient of daily gain. The coefficient of gain from the daily mean is not used because of its similarities with the Nash-Sutcliffe coefficient in this particular case. Instead, the coefficient of determination (R^2) is calculated as part of the hydrologic analysis.

The deviation of volume, *DV*, quantifies the difference in observed and predicted water volumes and is calculated:

$$DV = \frac{\sum_{i=1}^{n}(Vm - Vs)}{\sum_{i=1}^{n} Vm} \times 100\% \qquad [11]$$

where *DV* is the deviation of volume (%), *Vm* is the measured water yield for the period of comparison, and *Vs* is the modeled water yield for the period of comparison. The calibration and validation is considered satisfactory if the absolute value of *DV* is less than 10 percent. Donigian et al. (1984) indicated that HSPF calibration is considered to be very good if the absolute value of *DV* is less than 10 percent, and good when *DV* is between 10 and 15 percent.

The Nash-Sutcliffe coefficient, *NS*, measures how well the daily simulated flow corresponds with the measured flow. This coefficient is calculated:

$$NS = 1 - \frac{\sum_{i=1}^{n}(Qm - Qs)^2}{\sum_{i=1}^{n}(Qm - Q)^2} \qquad [12]$$

where *Qm* is the measured daily discharge, *Qs* is the simulated daily discharge, and *Q* is the average measured daily discharge. A *NS* value of 1.0 indicates a perfect fit, while a value of 0 indicates that the model is predicting no better than the average of the observed data. Daily flow calibration and validation is considered to be satisfactory if *NS* value is larger than 0.4.

The model calibration and validation performance results are summarized in **Table 6-5**. Note that during the period of model calibration or validation, those days with missing or problematic data were excluded, so the count of days indicates the number of days with valid flow data. In general, the model simulates daily flow reasonably well with R^2 and *NS* values of most of the stations above 0.5 for both calibration and validation analyses except for the Hobe Grove station.

Table 6-5. WaSh Model Calibration and Validation Performance Results.

Monitoring Station	S-46	Lainhart Dam	Cypress Creek Station	Hobe Grove Station	Kitching Creek Station
Calibration Results					
Period	1987–1996	1987–1996	1980–1986	1981–1985	1990–1996
Number of days	3193	3193	1680	1058	2192
DV (%)	–1.78	–0.83	–7.50	–14.67	0.21
NS	0.69	0.47	0.43	0.08	0.51
R^2	0.71	0.53	0.53	0.54	0.51
Validation Results					
Period	1997–2004	1997–2004	1987–1990	1987–1989	1997–2000
Number of days	2587	2587	990	687	1461
DV (%)	12.52	9.43	–2.87	10.66	9.09
NS	0.71	0.56	0.61	0.27	0.54
R^2	0.73	0.32	0.72	0.63	0.57

To aid in the evaluation of model calibration and validation performance, three types of plots are prepared:

1. Daily flow distribution: Plot of the distribution of the measured and modeled daily flow to visually examine the overall model performance. Particular attentions are paid to the low flow regime.
2. Double mass curve: To compare the measured and modeled daily flow in a cumulative manner along with increasing rainfall. This is a visual check of the *DV* calculated in **Table 6-5.**
3. Daily flow time series of modeled flow and observed flow for selected periods.

Figure 6-4 includes the three plots for the Lainhart Dam and S-46 stations, which provide the longest period of flow data for model calibration and validation. Panels **A** and **B** in **Figure 6-4** compare the frequency distribution of the modeled versus the observed daily flows. A slight high frequency of flow in the range of about 10 cubic feet per second (cfs) is predicted by the model at Lainhart Dam, possibly due to low flow leakage at the structure becoming significant but is not measured. The double mass curves for both stations (**Figure 6-4,** Panels **C** and **D**) show consistent model performance when comparing the patterns of the increase of modeled and measured flow with increasing rainfall. At Lainhart Dam, the model over-predicted flow for a 3-month period during the wet season of 1999. This has been attributed partly to the 9 percent of *DV* in **Table 6-5**. Panels **E** and **F** in **Figure 6-4** are the time-series plots of measured flow and modeled flow from 2000 through 2003. Overall, the figure shows that the WaSh model simulates daily flows over Lainhart Dam and S-46 stations reasonably well.

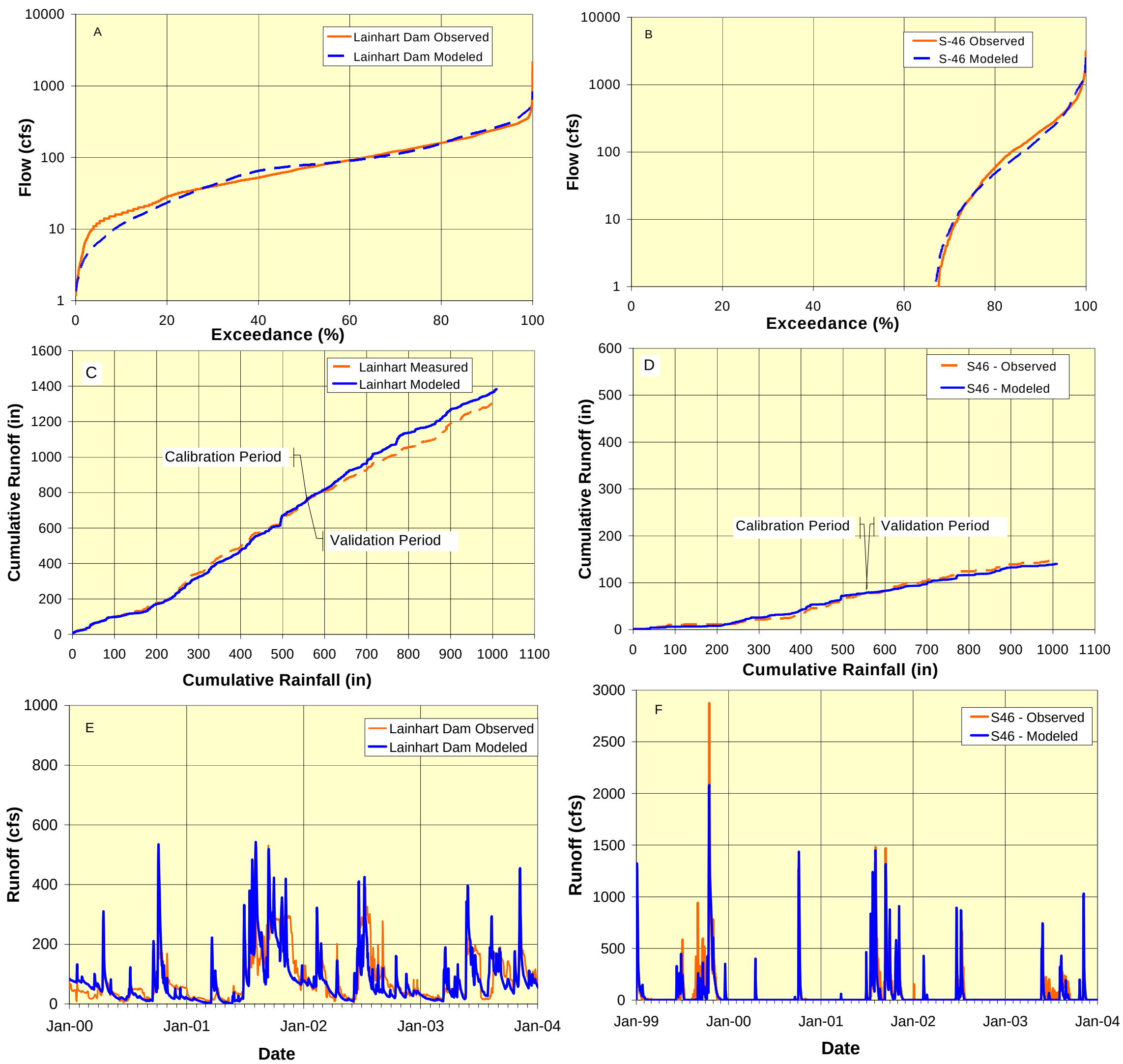

Figure 6-4. WaSh Model Calibration and Validation Plots for the Lainhart Dam and S-46 Stations (1/1/87–1/31/04).

Note: (**A**) Daily flow distribution at Lainhart Dam station, (**B**) Daily flow distribution at S-46 station, (**C**) Double mass curve at Lainhart Dam station, (**D**) Double mass curve at S-46 station, (**E**) Time-series plot at Lainhart Dam station (2000–2004), and (**F**) Time-series plot at S-46 station (1999–2004).

Calibration of the C-18 and Jupiter Farms portion of the model is difficult because the Jupiter Farms Basin, the C-18/Corbett Basin, and the Grassy Water Preserve Basin are hydrologically connected. The model represented the G-92 Structure by using the 'special structure' option. In its simplest form, the special structure consisted of a weir with a 12-foot elevation located in a reach consistent with its location along the C-18 Canal. When the water elevation in the C-18 Canal is above 12 feet, the weir structure will allow water from the C-18 Canal to flow out of the basin. This flow was subsequently used as input into the Jupiter Farms Basin as the model boundary condition. The flow rate is determined internally by the model, and is dependent on the prescribed weir configuration and the water elevation in the C-18 Canal. The width of the special weir was adjusted in a series of simulations until approximately 50 cfs of water flows during normal operations and a maximum of approximately 400 cfs flows under the flood control mode.

Similarly, for the inter-basin transfer of water from the Grassy Waters Preserve (West Palm Beach Water Catchment Area) into the C-18 Canal, a special structure was imposed in a separate model set up for the L-8 Basin to allow for a time series of flow as the boundary condition for the C-18 Basin model. Water flow was based on stage in the Water Catchment Area. According to a water budget model developed for the West Palm Beach Water Catchment Area (Sculley 1995), an annual contribution of 20,000 ac-ft of water from the Water Catchment Area to the C-18 Basin during April 1992 to March 1995 was used as a target to calibrate the special structure. The time-series plots for Lainhart Dam and S-46 stations (**Figure 6-4,** Panels **E** and **F**) indicate that the special structures provide a reasonable estimation of inter-basin transfers over the G-92 Structure and through the existing culverts in Grassy Waters Preserve into the C-18 Basin.

The Kitching Creek station collects flow from a large area dominated by forest and wetland. **Figure 6-5** presents the performance of the model calibrated and validated at Kitching Creek. Overall, the model is capable of simulating flow fairly well in this area. The daily flow distribution of the modeled flow matches the measured flow very well. The double mass curves are consistent with 0.21 percent of *DV* for calibration and 9.09 percent for validation shown in **Table 6-5**. However, the time-series plot (**Figure 6-5**, Panel **C**) did show that in 1998 there were a few significant events that are not predicted by the model. Such deviations are likely related to the poor quality rainfall data.

The plots for the Cypress Creek and Hobe Grove Ditch stations are shown in **Figure 6-6**. The plots for the Cypress Creek station are consistent with the model calibration and validation performance measures shown in **Table 6-5**. Model calibration and validation at the Hobe Grove Ditch station is considered to be fair for the total volume. Daily flow calibration, however, did not meet the performance criteria. This is likely due to the quality of the data collected at the site. The Hobe Grove Ditch dataset is obtained from a stage–flow relationship downstream from several culverts that discharge from Gulf Stream Grove (owned by the District) and the structure owned by the Hobe St. Lucie Water Control District. Measuring flows under these conditions is challenging due to the complexity of the hydrologic connections and grove operations along with slight tidal influence in the downstream area. The stage-flow relationship is not as accurate as other flow gauges in the District. For example, in 1987 the Hobe Grove Ditch station failed to collect accurate data during several significant storm events; these significant events were accurately recorded by the nearby Cypress Creek station (**Figure 6-6**, Panels **E** and **F**). In this case, model simulation is considered to be acceptable in spite of the poor quality rainfall data.

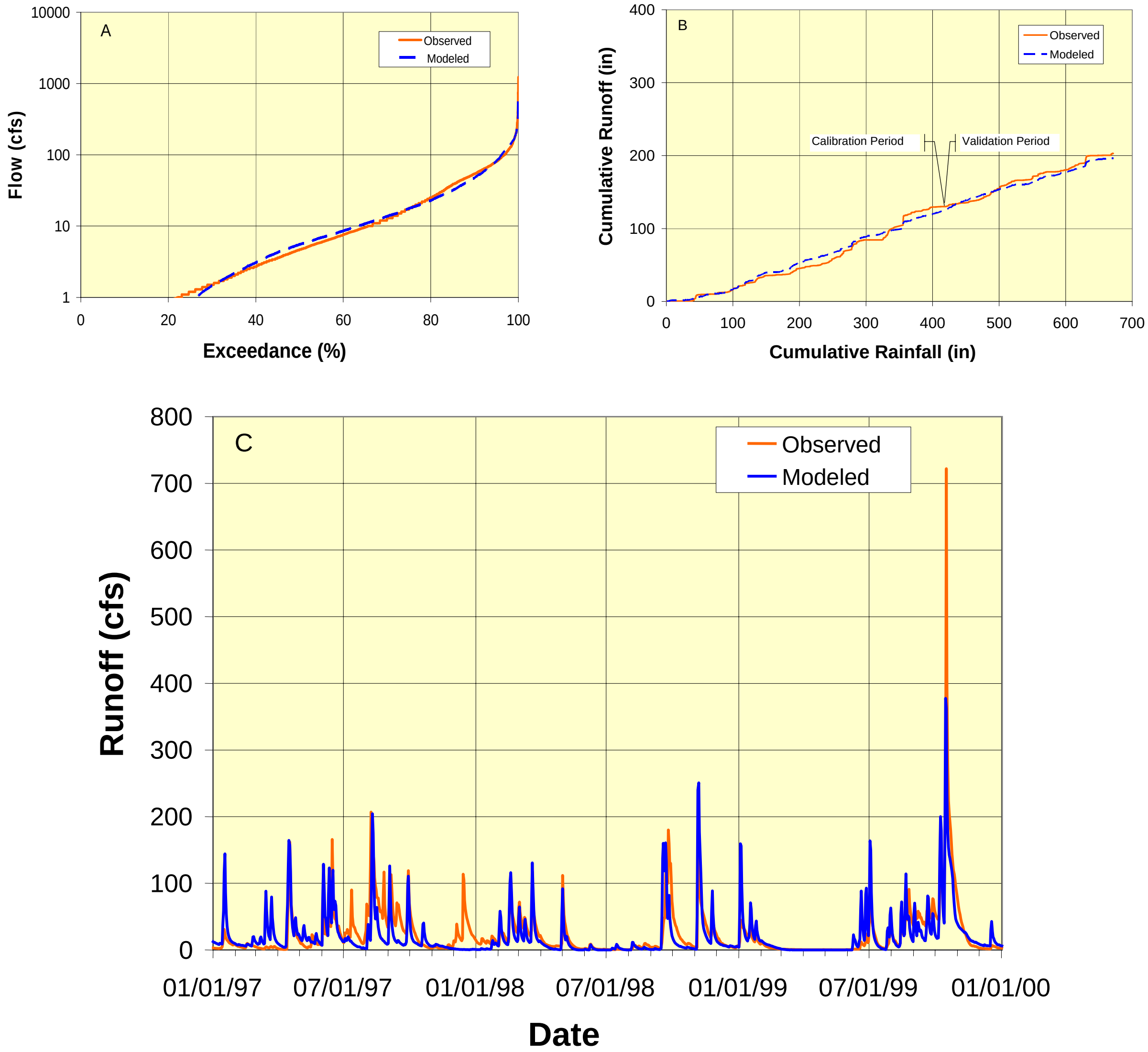

Figure 6-5. WaSh Model Calibration and Validation Plots at Kitching Creek Station (1990-2000).

Note: (**A**) Daily Flow Distribution, (**B**) Double Mass Curve, and (**C**) Time-Series Plot (1997-2000).

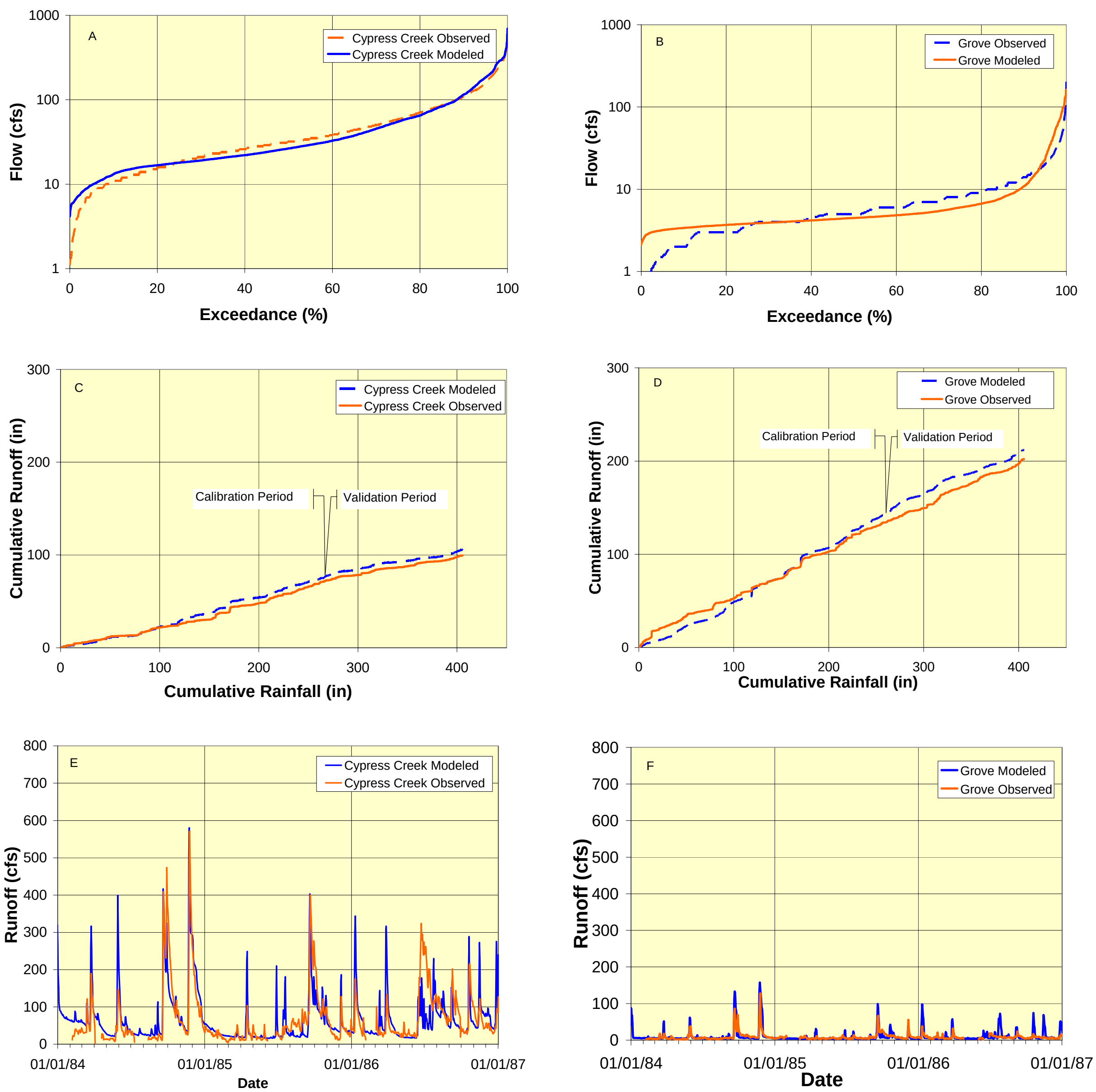

Figure 6-6. Model Calibration and Validation Plots at Cypress Creek and Hobe Grove Ditch Stations (1981–1990)

Note: (**A**) Daily Flow Distribution at Cypress Creek Station, (**B**) Daily Flow Distribution at Hobe Grove Ditch Station, (**C**) Double Mass Curve at Cypress Creek Station, (**D**) Double Mass Curve at Hobe Grove Ditch Station, (**E**) Time-Series Plot at Cypress Creek Station (1984–1987), and (**F**) Time-Series Plot at Hobe Grove Ditch Station (1984–1987).

The calibration of the groundwater level was conducted in the last step of WaSh model validation. **Figure 6-7** shows the time series of the observed and modeled water levels at the two groundwater monitoring wells used for validation. The cell hydrology simulated by the model is reasonable. Water level predictions could be further refined if the model is to be used for water level evaluations.

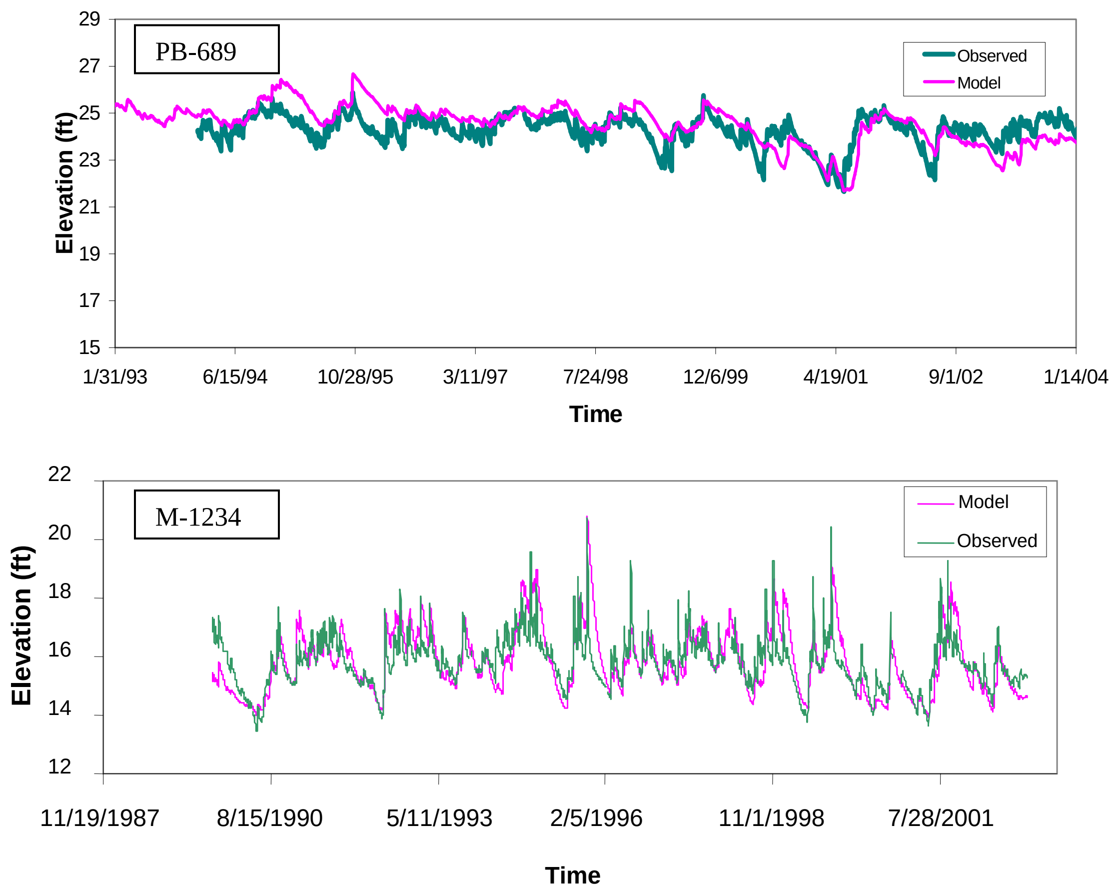

Figure 6-7. Observed and Modeled Water Levels in Groundwater Monitoring Wells PB-689 and M-1234. Land Surface Elevation is 24.43 feet at PB-689 and 21.15 feet at M -1234.

WaSh MODEL SIMULATION RESULTS

A final long-term simulation for the period from 1965 to 2003 was conducted after the calibration and validation of the Loxahatchee WaSh model was completed. Daily flows from each of the tributaries and each of the basins were averaged based on the model output of the 39-year POR simulation. **Table 6-6** is a summary of the data expressed as average daily flows and percentage of contributions from each of the basins (tributaries) into the Loxahatchee River and Estuary and the Northwest Fork. On average, the Northwest Fork receives about 65 percent of total freshwater flow into the entire Loxahatchee River and Estuary. Flow over Lainhart Dam (C-18/Corbett G-92 plus Jupiter Farms) accounts for about 45 percent of the total freshwater flow into the Northwest Fork, The next largest contributor is Cypress Creek (32 percent with Pal-Mar and Grove West combined). Kitching Creek at the monitoring station contributes about 8 percent, and Hobe Grove Ditch contributes about 5 percent. The remaining 8 percent is contributed from the areas that are not currently covered by flow monitoring stations. However, the actual freshwater flow contribution varies on a daily basis, depending on the specific hydrologic condition and water management practices. For example, there is little freshwater flow from S-46 during the dry season, whereas a disproportionately large quantity of fresh water is released from S-46 during a flood event.

Table 6-6. Flow Contributions from Each of the Basins and Major Tributaries into the Northwest Fork and Loxahatchee River and Estuary.

Basin	Average Daily Flow (cfs)	Flow Contribution	Northwest Fork Average Daily Flow (cfs)	Northwest Fork Flow Contribution
1. Kitching Gauge	17.4	5%	17.4	8%
2. North Fork	20.2	6%	--[a]	--[a]
3. Park River	5.1	2%	5.1	2%
4. Lox Estuarine	14.4	13%	--[a]	--[a]
5. C-18/Corbett G-92	69.7	22%	69.7	34%
5. C-18/Corbett S-46	51.3	16%	--[a]	--[a]
6. Historic Cypress Creek	7.0	2%	7.0	3%
7. Pal-Mar	57.7	18%	57.7	28%
8. Grove West	11.1	3%	11.1	5%
9. Grove East	10.6	3%	10.6	5%
10. Jupiter Farms	21.9	7%	21.9	11%
11. Wild and Scenic	6.9	2%	6.9	3%
Totals	320.3	100%	207.4	100%

[a] This basin does not contribute flows to the Northwest Fork of the Loxahatchee River.

Tables 6-7 and **6-8** summarize the mean monthly flow for each of the years from 1965 to 2003 for flows over the Lainhart Dam and the total flow into Northwest Fork covered by the four flow monitoring stations (Lainhart Dam station, Cypress Creek station, Hobe Grove station, and Kitching Creek station). For flows over Lainhart Dam (**Table 6-7**), mean monthly flows less than 35 cfs are shaded in red, and flows from 35 cfs to 65 cfs are shaded in yellow. These two flow ranges were selected because 35 cfs is the Minimum Flow and Level (MFL) for the Northwest Fork (SFWMD 2002b), and 65 cfs is defined as a flow target in the model for the development of the Northern Palm Beach County Comprehensive Water Management Plan (SFWMD 2002a). The Lainhart Dam data (**Table 6-7**) shows that a low flow period occurred from 1970 through 1978. For some years, mean monthly flows were less than 35 cfs even during the wet season (June through November). Another low flow period occurred from 1987 to 1990. Extended high flow years occurred from 1991 to 1999 and are shaded in light green. This pattern is consistent with the total Northwest Fork flows presented in **Table 6- 8**; mean monthly flows less than 70 cfs are shaded in red, and flows from 70 cfs to 130 cfs are shaded in yellow. The extended low-flow dry season periods in the 1960s, 1970s, and 1980s probably coincide with the period during which the Northwest Fork floodplain experienced the most significant saltwater encroachment. The high flow regime instituted in the 1990s has likely helped the floodplain hydrologic condition to recover from the preceding dry years.

Table 6-7. Mean Monthly Flows (cfs) over Lainhart Dam from 1965 to 2003.

	Month												
Years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Mean
1965	39	35	14	2	1	14	29	45	10	136	71	10	34
1966	90	76	34	22	53	211	220	127	88	203	63	37	102
1967	22	40	37	18	5	52	89	114	67	193	79	26	62
1968	14	13	7	2	19	302	173	136	197	274	147	62	112
1969	71	45	116	35	154	120	79	131	135	269	173	86	119
1970	113	104	208	237	97	155	112	64	56	71	29	18	105
1971	16	18	12	3	47	19	38	46	136	79	194	73	57
1972	44	39	21	41	191	204	85	50	33	33	68	28	70
1973	28	36	14	9	13	80	66	124	134	168	41	39	63
1974	150	39	45	14	8	131	151	156	54	134	57	63	84
1975	27	30	20	7	33	104	141	31	85	108	39	15	54
1976	9	20	27	5	106	114	30	67	182	72	72	28	61
1977	60	19	10	2	25	33	11	24	271	42	24	139	55
1978	72	30	32	6	14	145	140	145	88	168	263	190	108
1979	193	79	56	47	61	51	31	19	161	146	113	66	85
1980	47	58	39	20	33	29	86	34	32	80	26	17	42
1981	7	9	3	1	2	6	6	152	176	46	53	9	39
1982	12	26	150	200	166	241	124	93	110	145	302	182	146
1983	143	200	172	108	76	141	77	135	268	342	198	157	168
1984	123	86	127	84	102	124	65	48	179	120	196	150	117
1985	72	43	28	61	21	25	65	40	144	110	53	71	61
1986	125	42	102	82	14	93	112	72	76	80	92	99	83
1987	112	36	69	25	15	24	43	30	39	137	234	34	67
1988	57	47	42	14	29	91	116	184	75	18	14	7	58
1989	4	2	17	8	7	8	30	85	25	79	14	15	25
1990	11	6	7	10	7	15	17	77	93	151	22	16	36
1991	142	118	53	141	119	160	128	86	134	192	92	83	121
1992	49	117	66	56	20	122	125	188	217	164	198	95	118
1993	231	204	200	122	92	104	87	85	164	281	149	89	150
1994	96	142	84	82	70	143	114	223	273	209	278	285	166
1995	140	96	98	85	69	101	131	288	186	352	271	153	165
1996	82	73	156	116	137	140	176	96	128	163	123	78	123
1997	81	104	84	121	93	214	109	200	222	105	83	149	130
1998	148	204	161	88	106	53	84	66	208	133	289	102	136
1999	227	89	70	39	30	172	122	109	198	335	206	109	142
2000	81	74	62	91	34	19	40	18	52	174	29	23	58
2001	16	9	46	24	8	43	197	260	254	236	145	78	110
2002	69	125	60	44	15	116	185	57	40	51	43	36	70
2003	22	14	62	46	119	137	48	149	90	73	146	75	82
Monthly Mean	78	65	67	54	57	104	94	104	130	151	120	77	92

Note: Mean monthly flows less than 35 cfs are shaded in red, flows from 35 cfs to 65 cfs are shaded in yellow, flows greater than 65 cfs are shaded in light green.

Table 6-8. Mean Monthly Flows (cfs) into the Northwest Fork of the Loxahatchee River from Lainhart Dam, Cypress Creek, Hobe Grove Ditch, and Kitching Creek Stations from 1965 to 2003.

	Month												
Years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Mean
1965	89	106	56	16	10	44	95	129	34	457	259	53	112
1966	281	258	115	82	184	678	682	418	271	628	206	125	328
1967	83	132	122	68	35	158	270	336	210	607	238	94	197
1968	60	54	39	23	74	952	530	420	652	848	436	181	356
1969	204	136	346	108	438	372	256	395	426	876	523	253	363
1970	337	300	671	728	268	452	328	178	167	200	93	64	315
1971	58	64	48	28	148	68	121	135	403	246	633	239	182
1972	138	133	78	137	593	639	252	155	107	110	222	95	221
1973	99	121	59	44	56	242	205	405	408	517	134	126	202
1974	483	133	145	53	39	367	428	479	175	398	181	181	257
1975	89	95	65	36	107	299	436	107	260	323	124	59	167
1976	40	77	80	29	332	354	100	208	560	227	220	99	193
1977	193	67	44	22	95	97	41	78	853	142	84	406	177
1978	234	102	106	32	50	504	449	438	244	522	840	573	343
1979	544	226	152	139	164	147	91	62	517	483	342	192	255
1980	152	173	122	66	110	95	260	107	120	285	106	70	139
1981	39	53	25	18	16	26	28	476	542	154	188	43	134
1982	55	103	504	685	566	749	417	284	356	458	983	476	470
1983	455	656	552	330	203	418	202	388	853	1,074	606	487	517
1984	367	247	382	237	300	345	166	130	563	360	615	466	348
1985	192	116	83	183	65	89	185	115	448	350	160	210	183
1986	400	122	336	232	51	272	341	259	237	255	305	334	263
1987	335	113	218	84	62	88	134	89	143	441	741	119	214
1988	176	154	138	52	92	250	348	583	254	73	58	36	185
1989	30	24	62	38	30	32	88	233	88	246	58	58	83
1990	49	41	34	42	31	46	63	243	333	435	85	68	123
1991	495	374	161	417	345	481	361	267	400	594	282	240	368
1992	147	326	179	160	64	372	415	584	645	496	632	293	359
1993	740	619	598	340	244	274	233	237	447	867	416	238	437
1994	269	438	225	216	185	465	344	670	842	675	887	874	507
1995	417	275	284	227	172	256	343	858	568	1,146	812	401	482
1996	228	186	430	304	380	389	545	270	383	543	409	225	359
1997	247	300	241	372	262	689	343	594	671	314	224	446	392
1998	431	639	485	233	279	133	228	174	661	414	908	301	404
1999	749	261	181	103	84	495	343	299	599	1,079	606	314	427
2000	216	187	161	255	100	60	114	56	150	516	85	73	165
2001	53	37	126	66	39	149	477	794	792	668	387	203	318
2002	175	343	156	151	51	288	532	164	114	138	115	102	193
2003	65	47	202	136	372	392	126	354	235	184	381	181	224
Monthly Mean	241	201	205	166	172	314	280	312	403	470	374	231	281

Note: Mean monthly flows less than 70 cfs are shaded in red, flows from 70 cfs to 130 cfs are shaded in yellow, flows greater than 130 cfs are shaded in light green.

Because of the hydrologic variability during the past 39 years, the 39-year daily flow data at Lainhart Dam were analyzed to determine the daily flow distribution for each of the 12 months for all 39 years. This analysis indicates that the mean of the daily flow distribution in a month during the 39-year period of record does not match the median flow. The results are summarized in **Figure 6-8** which plots the median flow and the 75th percentile flow for each month. The 75th percentile flow represents the flow that is exceeded by only 25 percent of days in that month during the 39 years. Daily flow from Lainhart Dam is less than 50 cfs for 50 percent of time during the months of February, March, April and May. Flows in April and May are the lowest among all the months. This also shows the importance of flow augmentation during these low flow months.

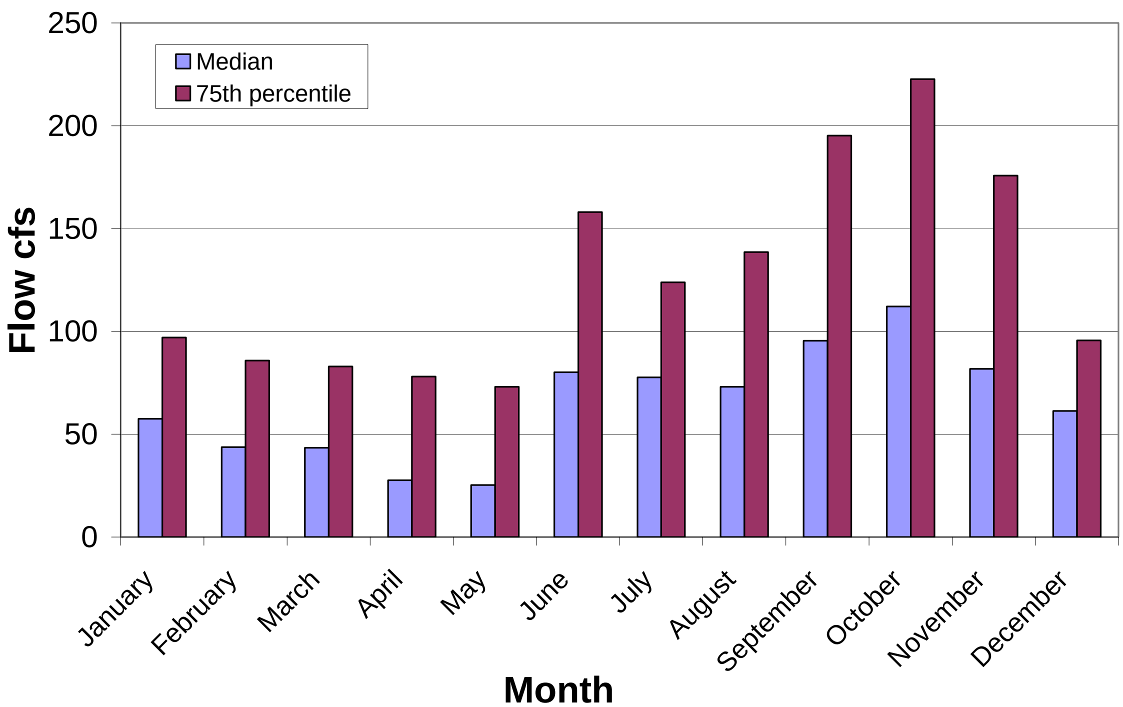

Figure 6-8. Median Monthly Flow and the 75th Percentile Monthly Flow over Lainhart Dam from 1965 to 2003.

MODELING SALINITY

THE HYDRODYNAMIC/SALINITY (RMA) MODEL DESCRIPTION

Salinity in the Northwest Fork of the Loxahatchee River and Estuary is controlled by both freshwater flows and tidal circulation, which represent the competition between river and ocean influences. A hydrodynamic/salinity (RMA) model was developed to study the influence of freshwater flows from the tributaries of the Northwest Fork and S-46 on the salinity conditions in the Loxahatchee River and Estuary. In parallel with model development, a data collection network was established to measure tide and salinity at five sites from the embayment area near the Jupiter Inlet (RM 0.70) to RM 9.12. The objective of salinity data collection and model development was to establish the relationship between salinity and the amount of freshwater flow. The requirement to the model is to predict average daily salinity over a long period of time such as 30 years under various project scenarios. The main focus of the data collection and salinity modeling has been on the upper reaches of the Northwest Fork of the Loxahatchee River.

The software programs used in developing the Loxahatchee River hydrodynamics/salinity model were RMA-2 and RMA-4 (USACE 1996). RMA-2 is a 2-D depth-averaged finite element hydrodynamic numerical model. It computes water surface elevations and horizontal velocity components for subcritical, free-surface flow in two-dimensional flow fields. RMA-2 computes a finite element solution of the Reynolds form of the Navier-Stokes equations for turbulent flows. Friction is calculated with the Manning's n or Chezy equation, and eddy viscosity coefficients are used to define turbulence characteristics. Both steady and unsteady state (dynamic) problems can be analyzed. RMA-2 has been used to calculate water levels and flow distribution around islands; flow at bridges having one or more relief openings, in contracting and expanding reaches, into and out of off-channel hydropower plants, at river junctions, and into and out of pumping plant channels; circulation and transport in water bodies with wetlands; and general water levels and flow patterns in rivers, reservoirs and estuaries.

The water quality model, RMA-4, is designed to simulate the depth-average advection-diffusion process in an aquatic environment. The model is used for investigating the physical processes of migration and mixing of a soluble substance in reservoirs, rivers, bays, estuaries and coastal zones. This model was used to evaluate salinity and the effectiveness of various restoration scenarios. For complex geometries, the model utilizes the depth-averaged hydrodynamics from RMA-2.

Figure 6-9 is a bathymetric map of the Loxahatchee Estuary. The estuary is shallow and well-mixed with the depth for most of the estuary ranging from 3 feet to 10 feet.

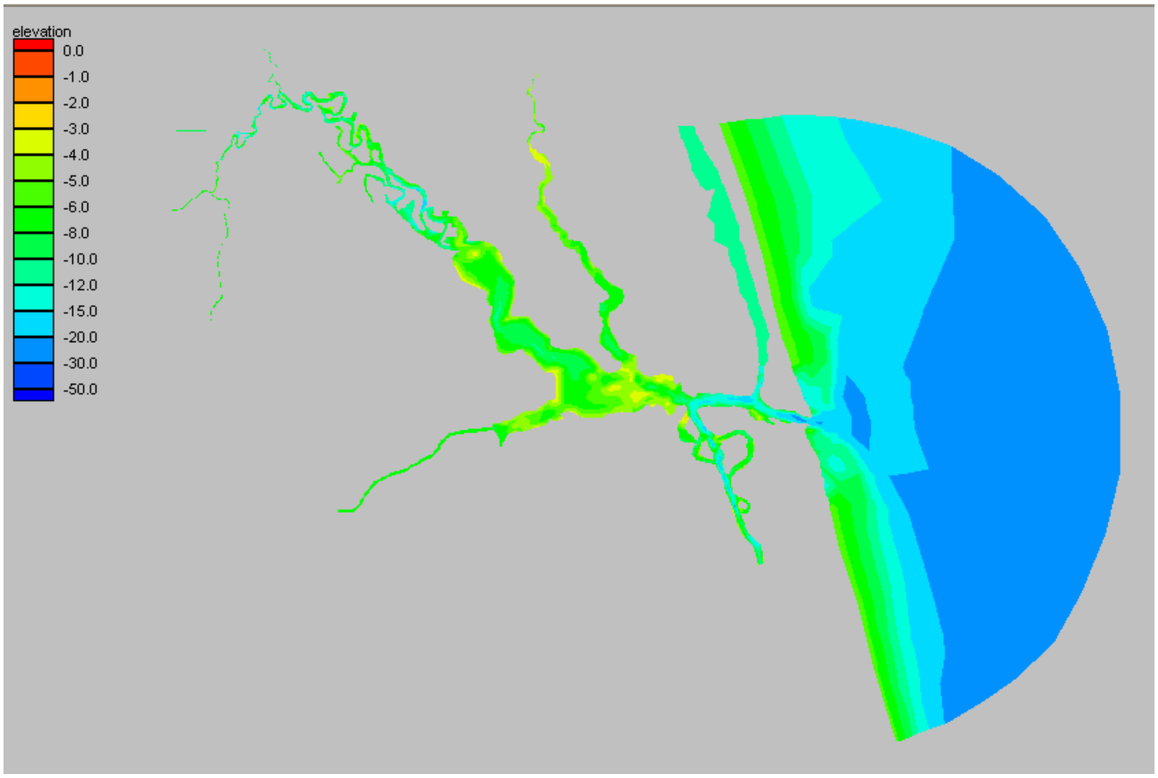

Figure 6-9. Bathymetric Map of the Loxahatchee River and Estuary with Elevation in Feet.

IMPLEMENTING THE RMA MODEL

Model Setup

The RMA model was updated in early 2004 using the most recent bathymetry, freshwater flow and tide data. The model mesh includes a total of 4,956 nodes with elevations derived from the survey data provided by the U.S. Geological Survey (USGS). **Figure 6-10** shows the RMA model mesh construction with 1,075 quadrilateral elements and 231 triangular elements. The red arrows in the figure indicate the locations where freshwater flows to the Northwest Fork are applied. The four tributaries that contribute freshwater flow to the Northwest Fork are Lainhart Dam, Cypress Creek, Hobe Grove Ditch, and Kitching Creek. The RMA model domain also includes the Southwest Fork and flows from the S-46 Structure. The RMA does not predict the amount of fresh water entering the system from the watershed or discharge structures. The freshwater flow amounts from these tributaries and structures are provided by the WaSh model or from recorded data from the flow gauges.

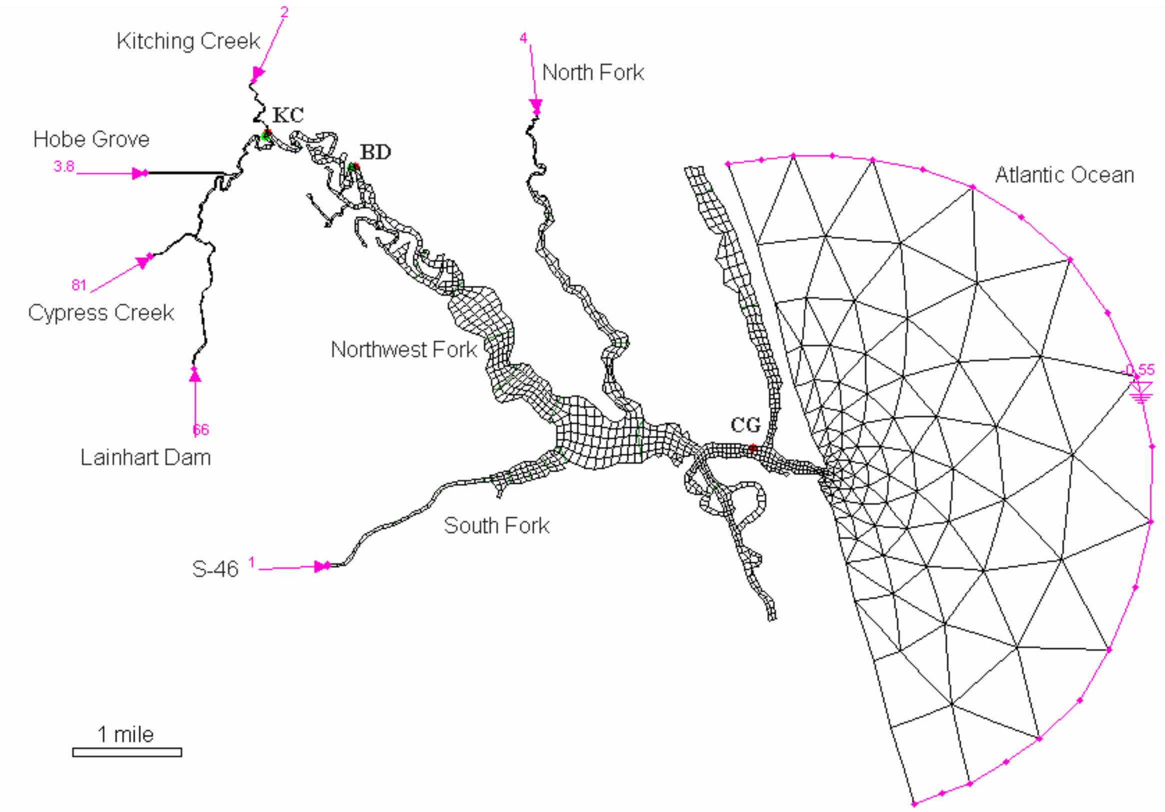

Figure 6-10. The RMA Model Domain Map.

Note: KC = Kitching Creek USGS Station; BD = Boy Scout Dock Station; CG = U.S. Coast Guard Station. The Red Arrows Indicate Where Freshwater Flows Are Provided to the Northwest Fork.

The meandering river channel pattern is one of the fundamental characteristics of the natural system of the Northwest Fork of the Loxahatchee River. Previous studies have demonstrated that restoring the natural oxbows to the Northwest Fork can effectively reduce saltwater intrusion into the historically freshwater reaches. The meandering river channel and oxbows of the Northwest Fork are preserved in the construction of the RMA model mesh.

Several natural river channel restoration projects have been implemented in the past decade to restore oxbows to the Northwest Fork. Salinity measurements taken before and after the implementation of the projects indicate that the oxbows can reduce the extent of saltwater intrusion into the Northwest Fork. The RMA model mesh contains the geographic features of the river channel. Depending on the time period, the model simulation can be conducted with the oxbow restoration projects completed for the post-project period or without the restored oxbows for the pre-project period. The current model mesh is also detailed enough to simulate the effectiveness of potential channel restoration projects in river reaches up to the Trapper Nelson's Interpretive Site (RM 10.50). The detailed geometry of the channel above Trapper Nelson's will be further refined after an ongoing GIS project is completed. On the ocean side, the model mesh was extended 3 miles offshore into the Atlantic Ocean to obtain a relatively stable salinity boundary condition (Hu 2004).

The RMA model was applied to establish the relationship between the amount of freshwater flow and the salinity regime in the Northwest Fork. This freshwater/salinity relationship is used to evaluate the various restoration scenarios.

Model Verification

A data collection program was implemented in conjunction with the preliminary RMA model design. A bathymetric survey of the Loxahatchee River was conducted by the USGS in early 2003. The Northwest Fork survey covered river reaches from RM 4.0 to Trapper Nelson's Interpretive Site (RM 10.50). Approximately 3 miles of the North Fork were also surveyed. In addition to the flow gauges located at Lainhart Dam and Kitching Creek, two additional gauges were established on Cypress Creek and Hobe Grove Ditch in November 2002. These four flow gauges monitor the majority of freshwater flows to the Northwest Fork. Four tide and salinity stations also have been deployed in the Loxahatchee Estuary since November 2002 by the USGS. An additional tide/salinity gauge was installed at RM 9.12 in October 2003 by the District's Water Supply Department. These five stations monitor the tide and salinity in the estuary continuously and record the data at 15-minute intervals. The data are retrieved at scheduled maintenance times and reported quarterly after quality assurance and quality control (QA/QC) has been conducted. To detect temperature and salinity stratification, three of the tide/salinity stations record salinity and temperature measurements at two water depths. The three sites with double temperature/salinity sensors are located at RM 9.12, Boy Scout Camp Dock (RM 5.92) and the U.S. Coast Guard Station near the Jupiter Inlet (RM 0.70). All sensors were installed at water levels below lower low tides to avoid exposure to air.

In addition to the tide and salinity measurements obtained from the USGS sites, the Loxahatchee River District (LRD) also has an estuarine data collection program at several additional locations that are not covered by the USGS monitoring network. The LRD uses multi-parameter datasondes to record time, dissolved oxygen, water depth, conductivity/salinity, pH and temperature. The meters are located near the bottom of the channel in order to track maximum salinity changes in the water column. The LRD data were collected at North Bay seagrass survey site (RM 1.48), Pennock Point seagrass survey site (RM 2.44), Northwest Fork near the mouth of Kitching Creek (RM 8.13), Station 66 in the Wild and Scenic Loxahatchee River, and Station 69 near the Indiantown Road (RM 14.93). To measure current velocity, the LRD contracted Scientific Environmental Applications to install two bottom mount Acoustic Doppler Current Profiler (ADCP) units at various locations in the estuary in 2003.

The Loxahatchee hydrodynamic/salinity (RMA) model was verified against field data for the period from May 1 to August 12, 2003. **Figure 6-11** shows the combined freshwater flow from four major tributaries to the Northwest Fork for this period. Average daily flow rates (cfs) from flow gauges on upper Northwest Fork at Lainhart Dam, Cypress Creek, Hobe Grove, and Kitching Creek were used for the calculation. Flow from S-46 into the South Fork was based on measurements at the S-46 Structure for the model simulation period.

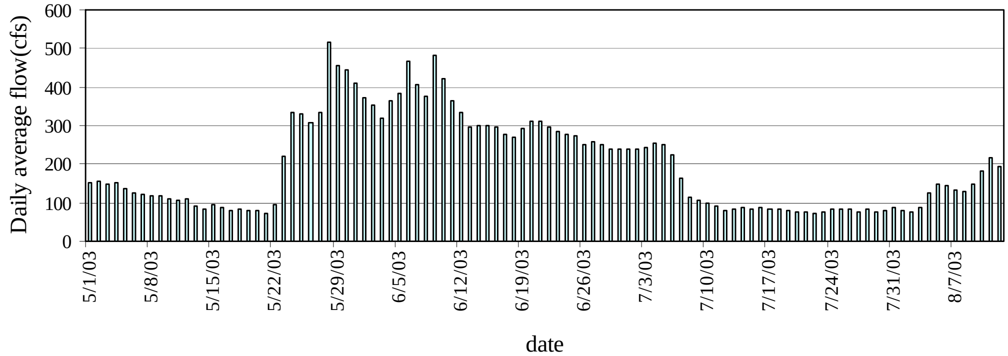

Figure 6-11. Combined Freshwater Flow from the Major Tributaries to the Northwest Fork of the Loxahatchee River for the Period May1 to August 12, 2003.

Figure 6-12 is a comparison of tidal data from the Coast Guard station (RM 0.70) with the RMA-2 model output for the same location. Because the two curves overlap when printed in the same chart, the model output and field data are plotted in separate charts using the same scale and grid lines for ease of comparison. For RMA-4 applications, a constant salinity of 35.5 parts per thousand (ppt) was applied on the ocean boundary.

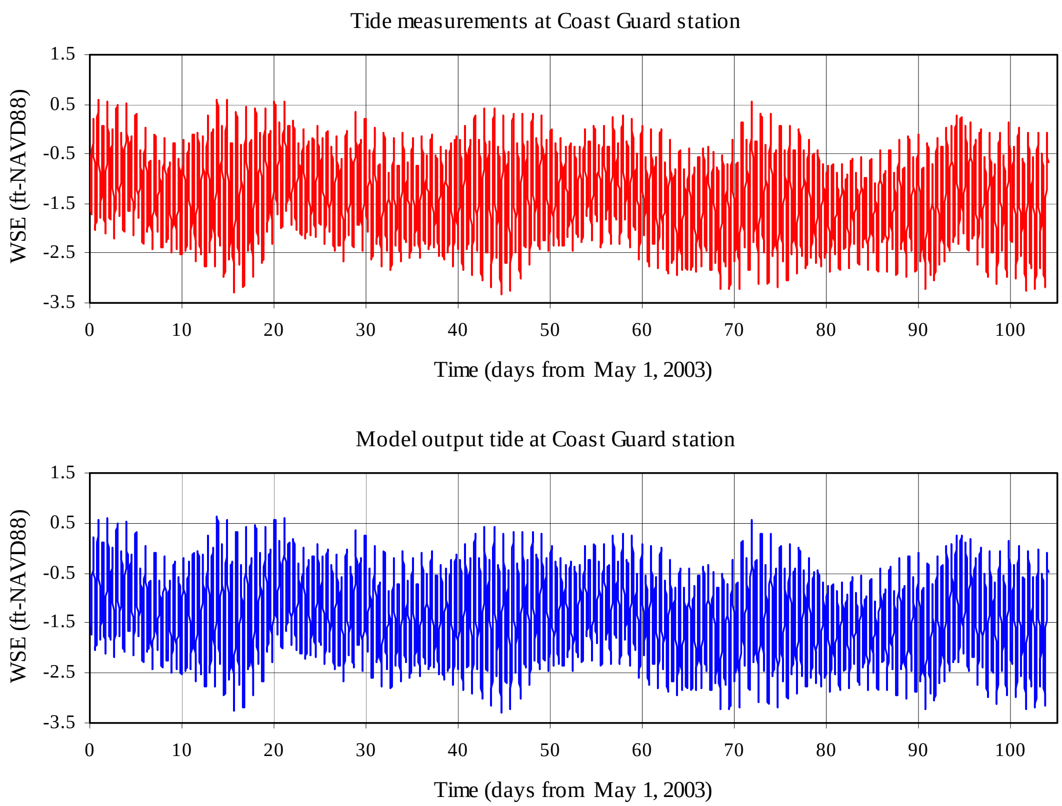

Figure 6-12. Tide Measurements at the Coast Guard Station (RM 0.70): Field Data and RMA Model Output. WSE = Water Supply and Environmental; NAVD = North American Vertical Datum 1988.

Field data and model output for tides at Boy Scout Dock (RM 5.92) and Kitching Creek (RM 8.13) are plotted in **Figure 6-13**. These two stations are approximately 2 river miles apart and there is no major tributary between these locations. Both field data and model output indicate that the tidal regimens at these two sites are similar in terms of range.

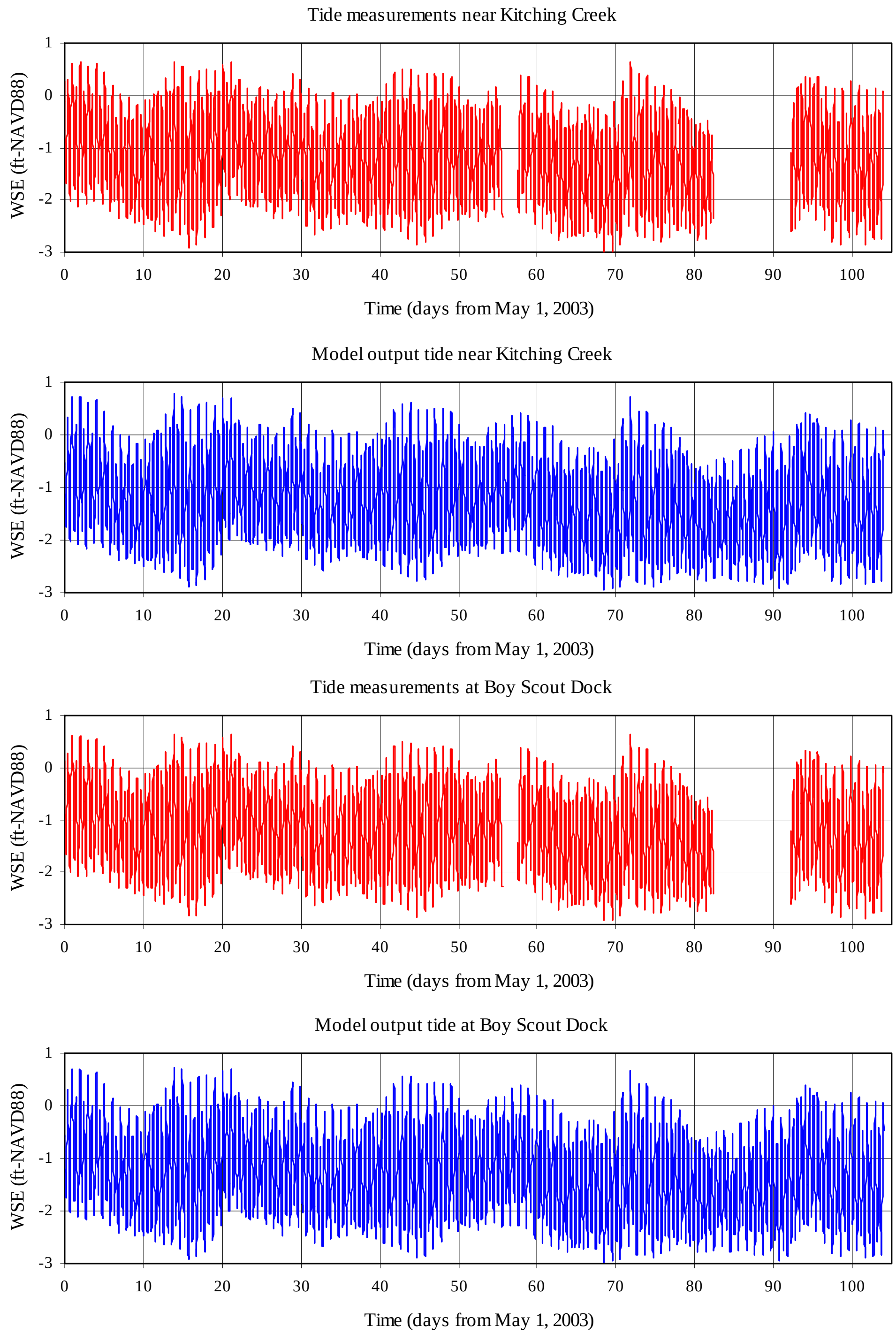

Figure 6-13. Tide Measurements at Kitching Creek Station (RM 8.13) and Boy Scout Dock (RM 5.92): Field Data and RMA Model Output. WSE = Water Supply and Environmental; NAVD = North American Vertical Datum 1988.

To more precisely evaluate RMA model accuracy, statistical analyses were conducted. The root mean square (RMS) error and the relative RMS error (RRE) statistics were used to evaluate model performance. The smaller the RMS, the better the model output tracks the field observation. A RMS error of zero is ideal. The RMS is the average of the squared differences between observed and predicted values:

$$RMS\ \text{Error} = \sqrt{\frac{1}{N}\sum_{n=1}^{N}\left(O^n - P^n\right)^2} \qquad [13]$$

where N = number of observed-predicted pairs

O^n = the value of the nth observed data

P^n = the value of the nth predicted data

The relative RMS error (RRE) provides another measurement of the model performance. A zero percentage RRE indicates a perfect match. The RRE is defined as the ratio of RMS error to the observed change:

$$RRE = \frac{RMS\ Error}{Observed\ \ \text{Change}} \times 100 = \frac{\sqrt{\frac{1}{N}\sum_{n=1}^{N}\left(O^n - P^n\right)^2}}{O_{\max} - O_{\min}} \times 100 \qquad [14]$$

where O_{max} = maximum value of observations

O_{min} = minimum value of observations

$(O_{max} - O_{min})$ = the range of the observation data

N = the total number of the observation records

Table 6-9 lists the RMS and RRE of the model tide output at two sites in the Northwest Fork and one site near the model boundary. CG is the station ID for the tide gauge at the Coast Guard station. BD and KC are station IDs for tide gauges at the Boy Scout Camp Dock and at the mouth of the Kitching Creek, respectively. The mean square errors (RMSs) were less than 2 inches at each of the three sites. The relative error (RRE) was less than 3 percent near the model boundary (CG) and was less than 5 percent at the two Northwest Fork stations.

Table 6-9. Root Mean Square (RMS) Error and Relative RMS Error (RRE) Statistics for the RMA Model Tide Output at Three Locations.

Station ID (RM)	No. of Observations	RMS (feet)	RRE (%)	Observed Range (feet)
CG (RM 0.70)	4983	0.1058	2.71%	3.90
BD (RM 5.92)	4423	0.1700	4.78%	3.56
KC (RM 8.13)	4423	0.1612	4.40%	3.66

Table 6-10 compares the model output and field observations in terms of maximum, minimum, and mean tidal values. The difference in mean tide over the entire 3-month simulation period was less than one-tenth of an inch near the model boundary (at the Coast Guard Station). The difference in mean tide at the two Northwest Fork stations was about an inch.

Table 6-10. Comparison of RMA Model Tide Output with Field Observations at Three Locations.

Station ID (RM)	Maximum Tide (ft)		Minimum Tide (ft)		Mean Tide (ft)	
	Observed	Modeled	Observed	Modeled	Observed	Modeled
CG (RM 0.70)	0.5900	0.6150	-3.3100	-3.2900	-1.3710	-1.3833
BD (RM 5.92)	0.6300	0.7230	-2.9300	-2.9590	-1.2104	-1.3316
KC (RM 8.13)	0.6500	0.7740	-3.0100	-2.9370	-1.1982	-1.2900

Figure 6-14 compares model output of depth-averaged salinity with actual field salinity measurements from instruments at fixed elevations. However, although these two quantities are similar, they do not represent the same physical parameters and are not directly comparable. The difference between the model output (representing depth-averaged salinity) and the actual field measurement (representing salinity at a fixed depth) could be significant when the system is stratified.

The salinity recorded at Boy Scout Dock increased to 10 ppt between Day 50 and Day 60 (**Figure 6-14**). This sudden salinity increase does not seem to be related to or supported by data from other field records. A salinity of 10 ppt usually occurs at this site when freshwater flow is below 100 cfs. The flow gauges actually recorded over 200 cfs for this period. The salinity record from the adjacent Kitching Creek station is also inconsistent with the salinity increase at the Boy Scout Dock station. Previous studies indicated that 10 ppt at Boy Scout Dock station would have raised salinity at Kitching Creek station to 2 ppt or above (Russell and McPherson 1984); however, there was no salinity increase for Kitching Creek during this time period (see the Kitching Creek chart in **Figure 6-14**). Therefore, the accuracy of the salinity field measurements at Boy Scout Dock between Day 50 and Day 60 is questionable.

Both RMA-2 and RMA-4 are two-dimensional depth-averaged models. When the system is minimally stratified, such as the condition near the Jupiter Inlet at the Coast Guard station, the modeled salinity output tracks the field salinity data rather closely. However, when the system is highly stratified, as occurs in certain areas, the modeled salinity output for that area could give a smaller salinity variation between high tide and low tide when compared to the field salinity measurements from fixed depths (see the Boy Scout Dock chart in **Figure 6-14**).

The RMA-4 output is depth-averaged salinity, which differs from salinity measured by a transducer at a fixed elevation. The conductivity transducers were installed at elevations that would remain below the water surface at low tide. Because the range between higher high and lower low water is close to 4 feet and the overall water depth is only about 6 feet to 10 feet, the conductivity transducers would be situated in the lower water column during high tide. Under these conditions, the instrument would take measurements from the surface layer at low tide and from the bottom layer at high tide. If the system is well mixed (i.e., no stratification), then there should be no difference between the modeled depth-averaged salinity and field salinity measurements. However, when the system is stratified, the daily salinity variation recorded by the instruments would be wider than the daily salinity variation output from depth-averaged salinity model.

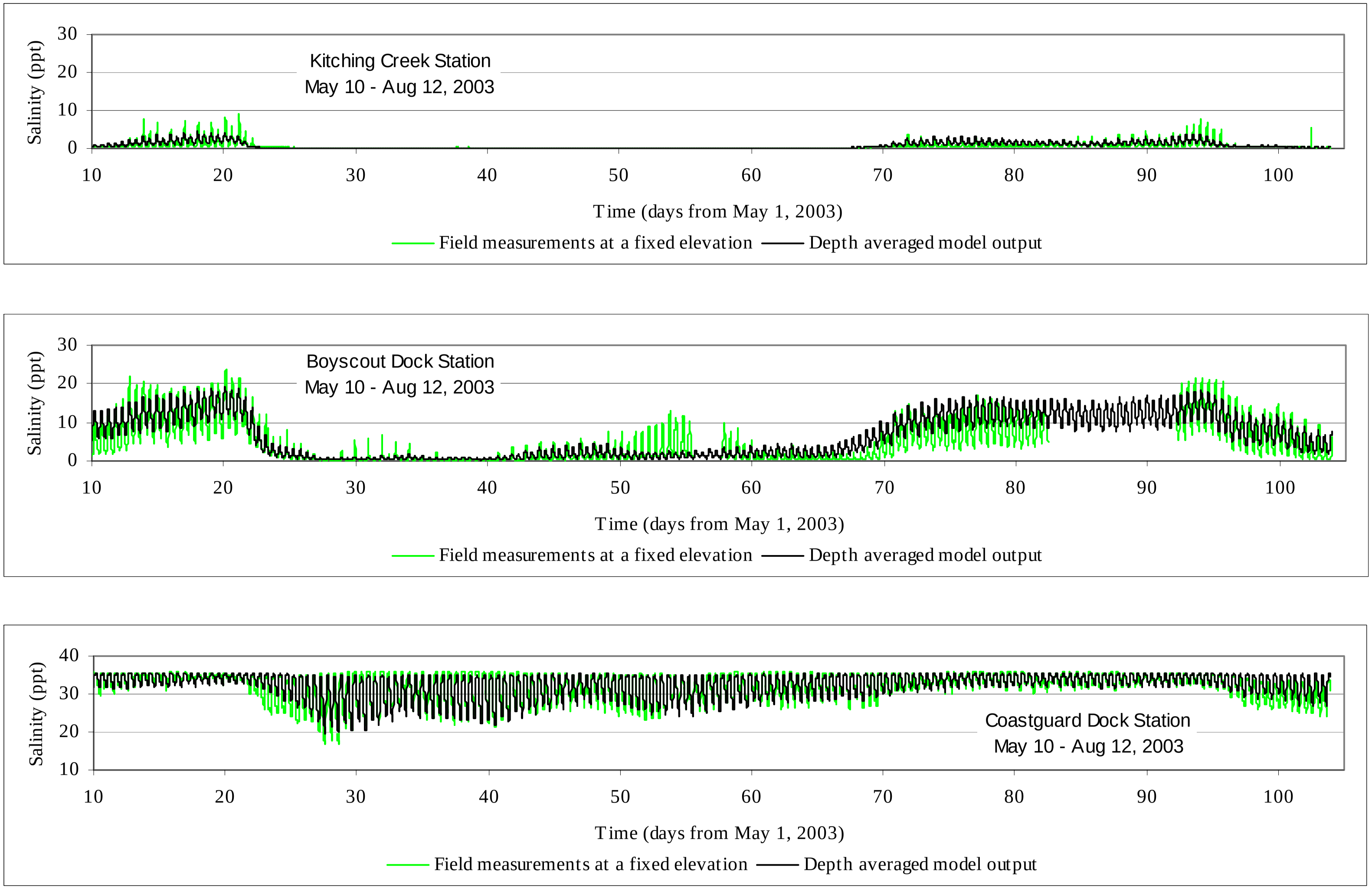

Figure 6-14. Comparison of Model Output of Depth-Averaged Salinity (ppt) with Field Measurements at Fixed Elevations of Salinity (ppt) in the Water Column at Three Locations.

Table 6-11 lists the statistics of model salinity output accuracy analysis at Kitching Creek, Boy Scout Camp Dock, and the U.S. Coast Guard Stations**. Table 6-12** lists the statistical characteristics of both model salinity output and the observed values.

Table 6-11. Root Mean Square (RMS) Error and Relative RMS Error (RRE) Statistics for the RMA Model Salinity Output at Three Locations.

Station ID (RM)	No. of Observations	RMS (ppt)	RRE (%)	Observed Range (ppt)
KC (RM 0.70)	4509	0.6047	6.65%	9.10
BD (RM 5.92)	3951	2.5454	10.76%	23.65
CG (RM 8.13)	4507	1.8713	9.70%	19.30

Table 6-12. Comparison of RMA Model Salinity Output with Field Observations at Three Locations.

Station ID (RM)	Mean Salinity (ppt)		Maximum Salinity (ppt)		Minimum Salinity (ppt)	
	Observed	Modeled	Observed	Modeled	Observed	Modeled
KC (RM 0.70)	0.7507	0.5732	4.3670	9.2000	0.1500	0.1000
BD (RM 5.92)	6.3726	4.6928	19.0380	23.8000	0.2220	0.1500
CG (RM 8.13)	32.3625	31.9756	35.4250	36.0000	19.5460	16.7000

The most likely reason for the salinity differences between RMA model predictions and field measurements is that there is additional freshwater flow into the system that bypasses the four stations on the river and the major tributaries. Such additional sources of fresh water may include overland flow and groundwater seepage into the system. A groundwater monitoring network that was established in 2003 indicates active exchanges between the river and the groundwater table. The model predicted higher salinity at the beginning of dry periods when the groundwater tables are still relatively high and therefore provide additional fresh water to the system. Including groundwater input in the model will likely increase the accuracy in salinity prediction. The current model, without the input of groundwater input and overland flow, tends to be conservative (predicting higher salinity).

The current RMA model does not include driving forces such as wind, precipitation/evaporation, and the exchange between the river and the groundwater which can be significant in the upper river reaches. The model verification simulation, which only was driven by major tributary freshwater input and ocean tide, was able to predict the tide regimen rather accurately and predict the trend of salinity changes over the 3-month simulation period that included both low and high freshwater input to the estuary. This indicates that tide and the amount of freshwater flow to the estuary are the two most dominant factors that affect the salinity regimen in the upper Northwest Fork.

RMA MODEL SIMULATION RESULTS

The tidal circulation and salinity structure of estuaries involves competition between freshwater river flows and ocean influences. River flow persistently adds fresh water to the estuary, however saltwater may still penetrate far inland due to gravitational and diffusive fluxes (MacCready 2004). Although there are other factors in addition to tide and freshwater flows that affect the salinity regime, the analysis of the field data from the Loxahatchee River suggests that tide and freshwater flow are the two most important factors that determine the salinity conditions in the Northwest Fork (Hu 2004). To establish the relationship between freshwater flow and salinity in the Northwest Fork of the Loxahatchee River, the RMA model was used in 12 modeling scenarios where the amount of total freshwater flow from all three forks of the Loxahatchee River into the estuary was held constant for rates varying from 40 cfs at the low flow end to 7,000 cfs at the high flow end. These flow rates were determined based on an analysis of freshwater flows simulated by the watershed model. During RMA model output processing, 20 study sites were identified for ecological assessment where salinity predictions are needed. Information about study and assessment sites is provided in **Table 6-13**. Sites noted as USGS stations are locations where tide and salinity measurement data are collected by the U.S. Geological Survey as discussed in the previous sections. **Figure 6-15** shows the locations of the 20 assessment sites.

Table 6-13. The 20 Salinity and Ecological Assessment Sites.

Coordinates[a]		Site		Description
X (feet)	Y (feet)	Station ID	River Mile	
955325	951200	CG	0.70	USGS Coast Guard
951456	952232	SGNB	1.48	Seagrass site - North Bay
949616	951344	SGSB	1.74	Seagrass site - Sand Bar
949538	950648	PD	1.77	USGS Pompano Drive
945680	951761	SGPP	2.44	Seagrass site - Pennock Point
945105	953335	O1	2.70	Oyster site 1
942902	954999	O2	3.26	Oyster site 2
942332	957383	O3	3.74	Oyster site 3
940923	958927	O4	4.13	Oyster site 4
938854	961625	O5	4.93	Oyster site 5
936681	963169	O6	5.45	Oyster site 6
935708	965258	BD	5.92	USGS Boy Scout Dock
935406	964872	RM 6	6.0	River mile 6.0
934835	965534	RM 6.5	6.5	River mile 6.5
934538	966065	RM 7	7.0	River mile 7.0
934679	966363	VT9	7.1	Vegetation Transect 9
933306	966580	RM 7.5	7.5	River mile 7.5
931920	966458	RM 8	8.0	River mile 8.0
931399	966948	KC	8.13	USGS Kitching Creek
929733	964696	RM 9	9.12	USGS River Mile 9.1

[a] Coordinates are in State Plane Florida East NAD83.

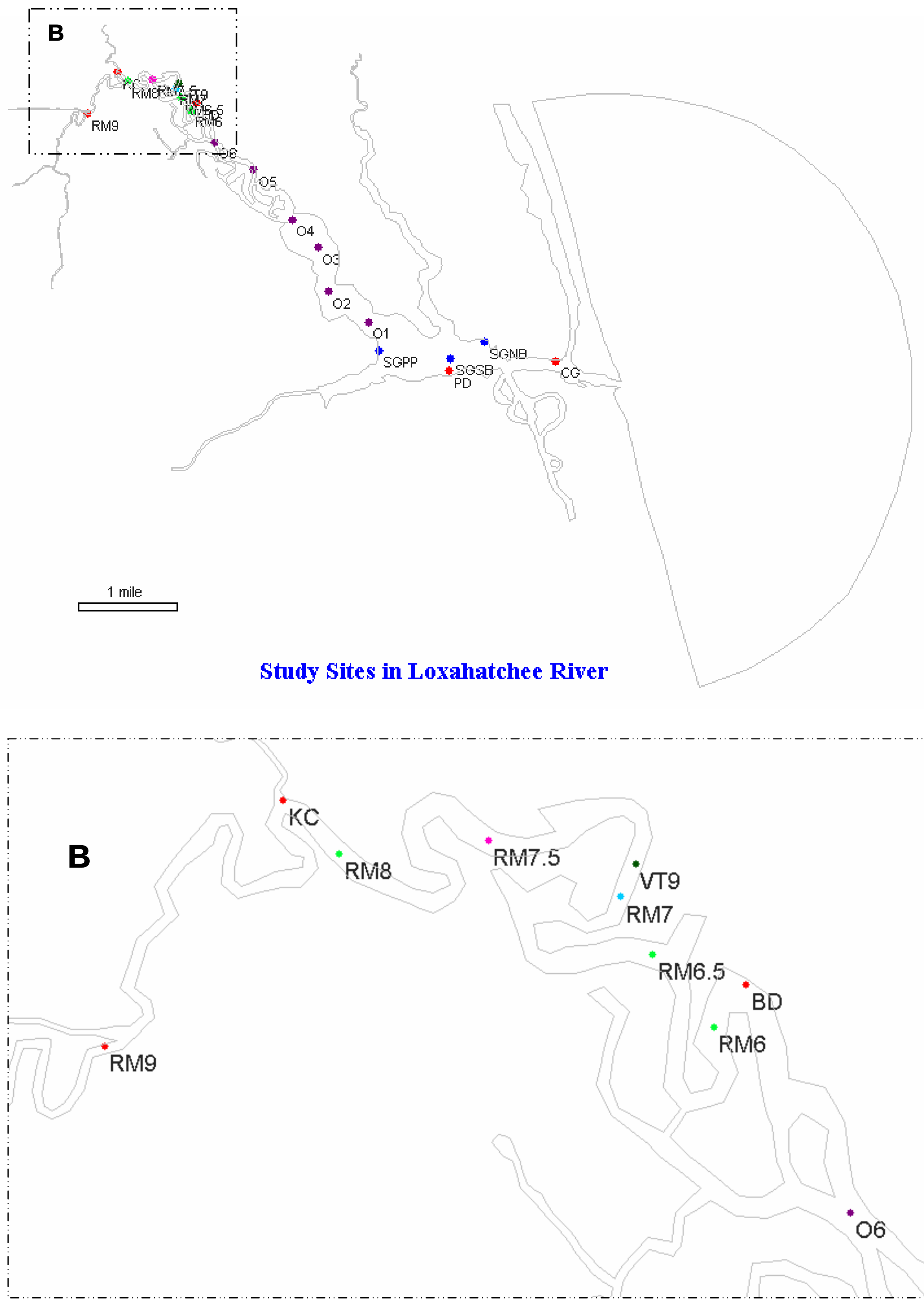

Figure 6-15. Location of the 20 Salinity and Ecological Assessment Sites.

Note: Red dots represent the USGS sites; blue dots represent seagrass sites; purple dots represent oyster sites; and green dots represent vegetation sites.

The objective of the RMA model is to establish a relationship between the amount of freshwater flow and tidally averaged salinity. The RMA model output was averaged over a lunar month that includes a full lunar tidal cycle with both spring and neap tides. Thus, these results reflect the daily averaged salinity under an average tidal condition.

Table 6-14 is a summary of the RMA model output of average salinity for 12 flow scenarios at each of the 20 sites. Regression analysis of the results yielded regression equations with excellent curve fitting. The best fit (R^2 = 0.999 for all the 20 sites) was achieved with exponential functions in the form of

$$Y = Y_0 + a\, e^{-bX} \quad [15]$$

where X is freshwater flow in cubic feet per second and Y is salinity in parts per thousand.

Table 6-14. Tidally Averaged Salinity (ppt) vs. Freshwater Flow (cfs) for the 20 Study Sites in the Loxahatchee River.

River Mile and	Freshwater flow to the Northwest fork in cfs											
Site Name	32	56	79	119	159	238	397	636	954	1908	3815	5564
RM 0.7 (CG)	34.6	34.4	34.1	33.7	33.3	32.5	31.0	28.8	26.1	19.3	10.1	5.0
RM 1.48 (SGNB)	34.1	33.6	33.1	32.4	31.6	30.1	27.4	23.8	19.6	10.9	3.1	0.6
RM 1.74 (SGSB)	33.9	33.3	32.7	31.8	30.9	29.1	26.0	21.8	17.3	8.5	1.9	0.3
RM 1.77 (PD)	33.8	33.2	32.7	31.7	30.8	29.0	25.8	21.6	17.0	8.3	1.8	0.3
RM 2.44 (SGPP)	33.2	32.3	31.5	30.1	28.8	26.4	22.2	17.1	12.1	4.3	0.6	0.2
RM 2.7 (O1)	32.7	31.7	30.6	29.0	27.4	24.5	19.6	14.0	9.0	2.5	0.4	0.2
RM 3.26 (O2)	32.0	30.5	29.0	26.8	24.8	21.1	15.4	9.6	5.2	0.9	0.2	0.2
RM 3.74 (O3)	31.1	29.2	27.4	24.7	22.2	18.0	11.8	6.3	2.8	0.4	0.2	0.2
RM 4.13 (O4)	30.5	28.3	26.2	23.1	20.4	15.9	9.6	4.6	1.8	0.3	0.2	0.2
RM 4.93 (O5)	27.8	24.4	21.5	17.3	13.9	9.1	3.9	1.2	0.4	0.2	0.2	0.2
RM 5.45 (O6)	25.8	21.6	18.1	13.5	10.0	5.6	1.8	0.5	0.2	0.2	0.2	0.2
RM 5.92 (BD)	23.6	18.8	15.0	10.3	7.1	3.4	0.9	0.3	0.2	0.2	0.2	0.2
RM 6	23.2	18.3	14.4	9.6	6.5	3.2	0.9	0.3	0.2	0.2	0.2	0.2
RM 6.5	20.4	15.0	11.0	6.5	4.0	1.6	0.4	0.2	0.2	0.2	0.2	0.2
RM 7	17.1	11.4	7.5	3.9	2.0	0.7	0.2	0.2	0.2	0.2	0.2	0.2
RM 7.06 (VT9)	16.8	11.0	7.2	3.6	1.9	0.6	0.2	0.2	0.2	0.2	0.2	0.2
RM 7.5	14.2	8.5	5.1	2.2	1.0	0.3	0.2	0.2	0.2	0.2	0.2	0.2
RM 8	10.6	5.5	2.9	1.0	0.5	0.2	0.2	0.2	0.2	0.2	0.2	0.2
RM 8.13 (KC)	9.7	4.9	2.5	0.9	0.4	0.2	0.2	0.2	0.2	0.2	0.2	0.2
RM 9	4.2	1.4	0.5	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2

The freshwater flow versus salinity relationships pesented in **Table 6-14** are plotted in **Figures 6-16** and **6-17**. Each curve in **Figure 6-16** represents the flow/salinity relationship for each of the 20 sites. For each site, salinity (ppt) increases as freshwater flow (cfs) decreases.

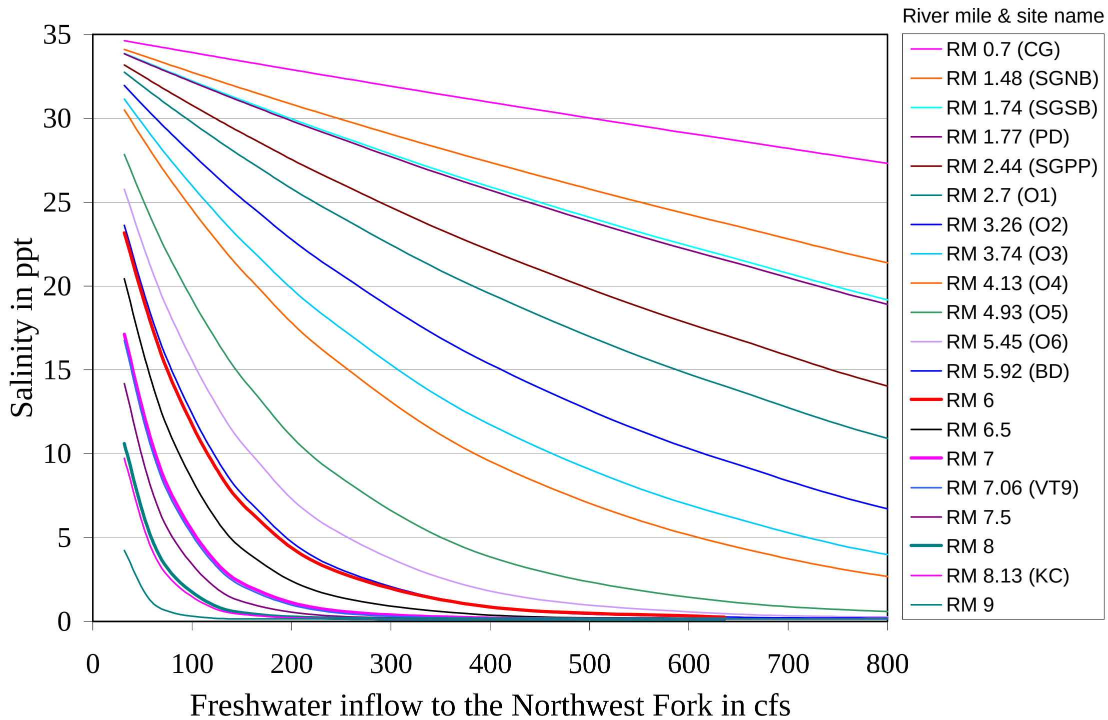

Figure 6-16. The Relationship between Freshwater Flow (cfs) and Salinity (ppt) at 20 Sites.

In order to show the details of salinity variation at low flow end, the charts were plotted only for flows up to 800 cfs. For salinity regimens with freshwater flows greater than 1200 cfs, either **Table 6-14** or Equation [15] can be used to determine the salinity value. The curves in **Figure 6-17** represent the salinity gradients at various levels of freshwater flow. Each line represents the spatial salinity distribution for a particular flow scenario.

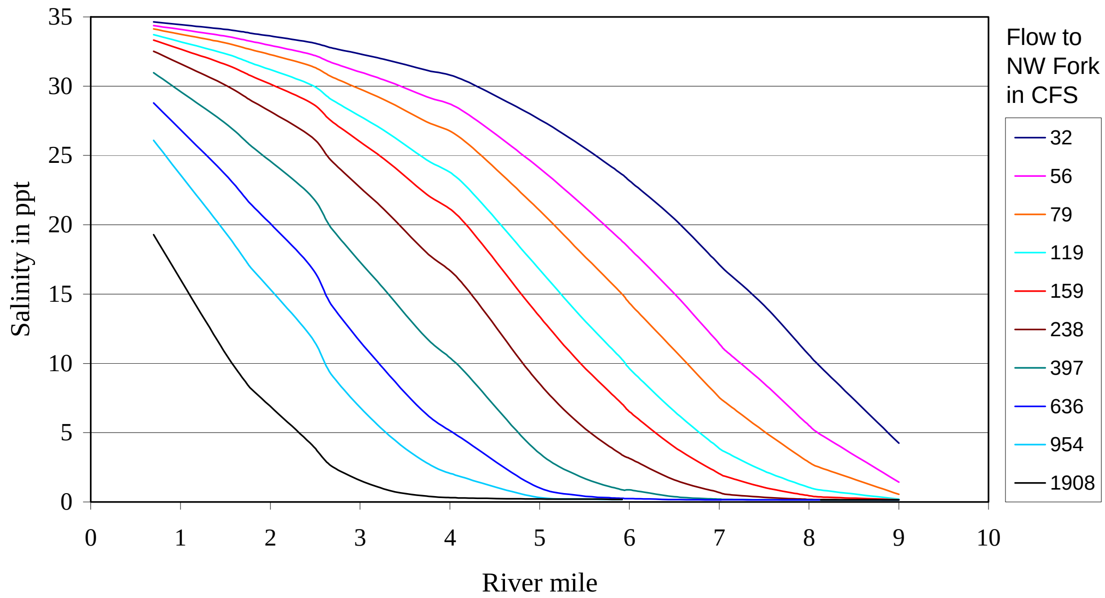

Figure 6-17. Salinity Gradients by River Mile Location under Various Freshwater Flow Conditions.

Although Equation [15] expresses salinity as a single dependent variable function, there are other driving forces that affect salinity including tide, wind, flux between river and groundwater, precipitation, and evaporation. However, the analysis of field data indicated that freshwater flow is the most important factor affecting salinity. When salinity is plotted against freshwater flow, the data points form a clear trend line. Comparing results from Equation [15] with actual field data provides a reality check. **Figures 6-18** through **6-21** compare the model results from Equation [15] with actual field measurements. As expected, deviations from the modeled flow/salinity curve indicate the existence of other driving forces that affect salinity. Nonetheless, the correlation between salinity and freshwater flow is significant. Another factor that could cause deviations is that the system is under constant transition in response to the changes in the driving forces. Therefore, it is rare for the system to reach equilibrium as the case in the constant flow simulations. The overall trend of the field measurements shows a strong correlation between the amount of freshwater flow and salinity throughout the estuary.

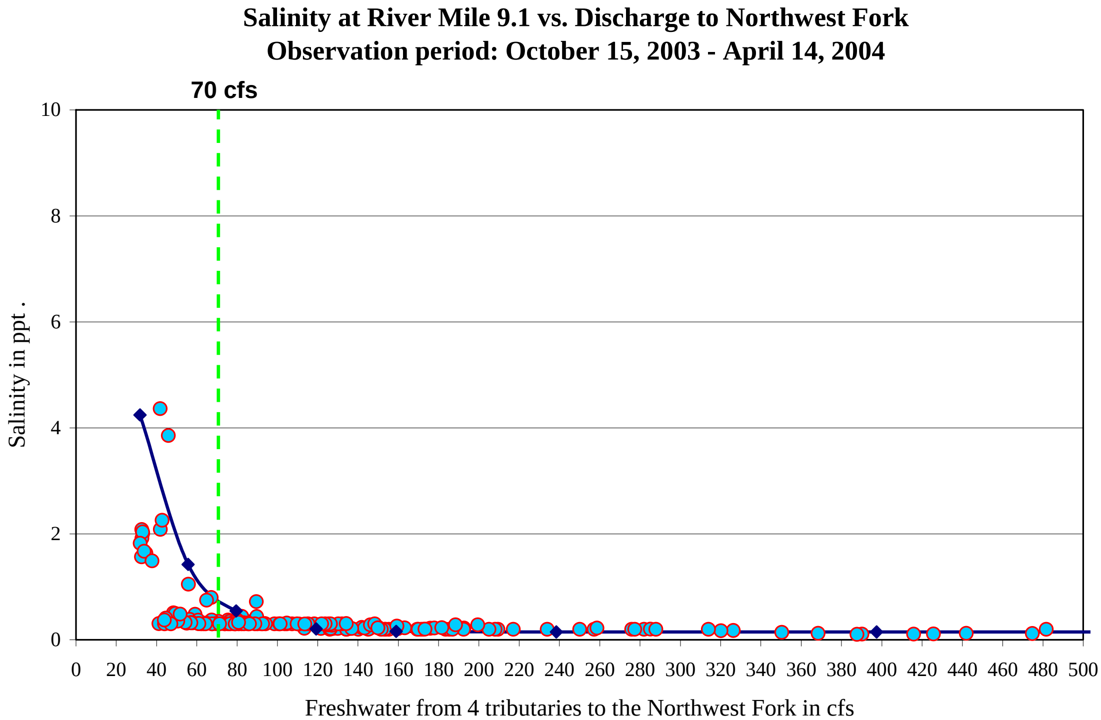

Figure 6-18. The Effects of Freshwater Flow on Salinity at RM 9.1 from October 15, 2003 to April 14, 2004.

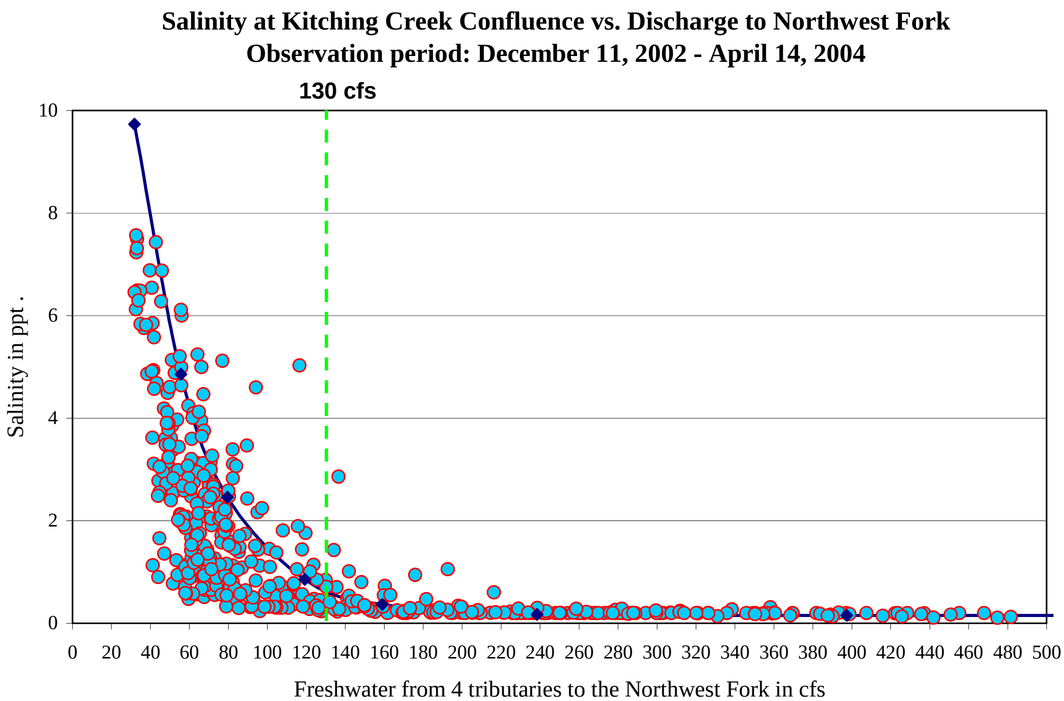

Figure 6-19. The Effects of Freshwater Flow on Salinity at Kitching Creek (RM 8.13) from October 15, 2003 to April 14, 2004.

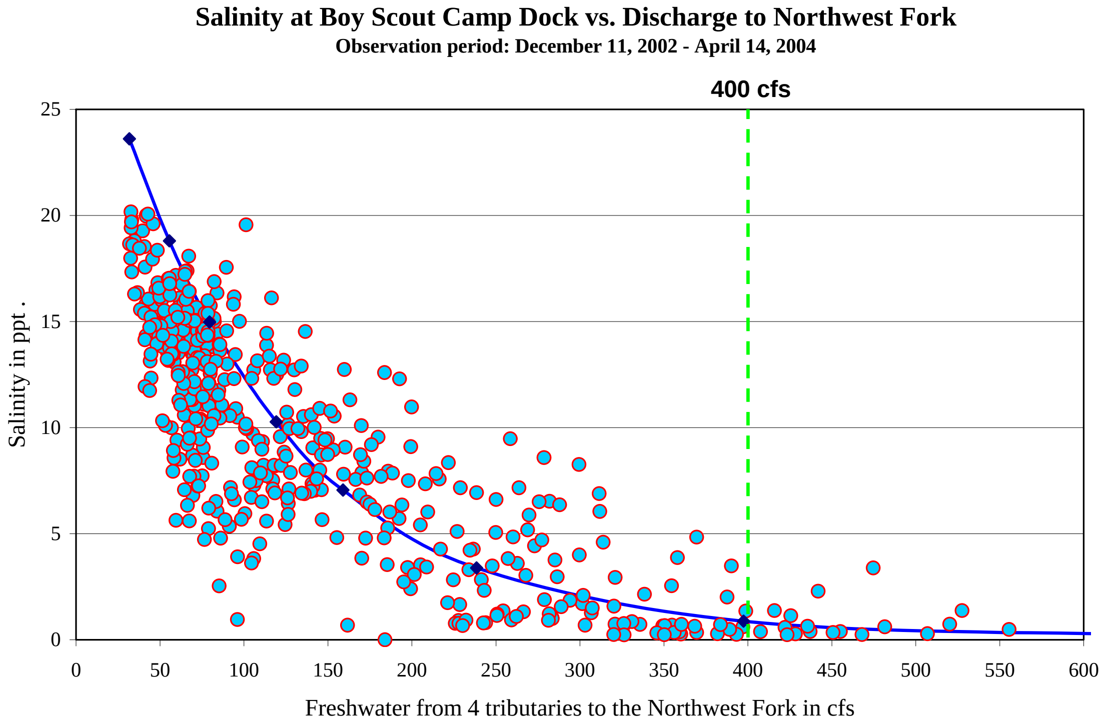

Figure 6-20. The Effects of Freshwater Flow on Salinity at Boy Scout Dock (RM 5.92) from December 11, 2002 to April 14, 2004.

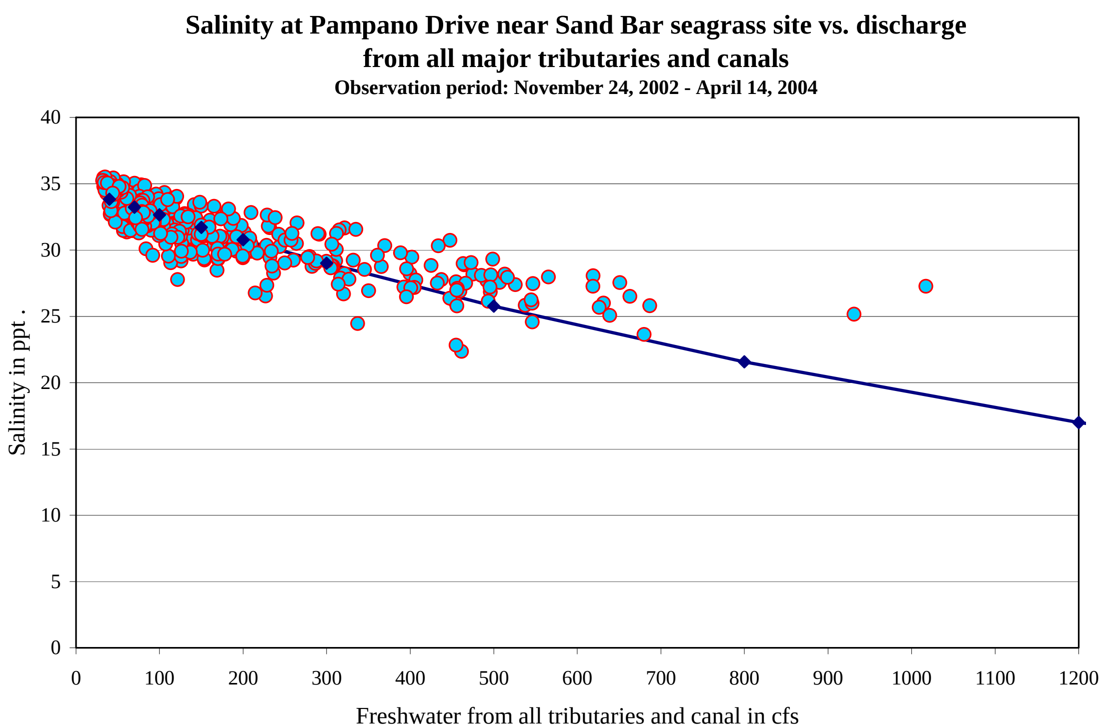

Figure 6-21. The Effects of Freshwater Flow on Salinity in the Embayment near Pompano Drive (RM 1.77) from November 24, 2002 to April 14, 2004.

Freshwater flows to the Northwest Fork from the four major tributaries, several small tributaries, and overland flow were modeled. If the flows from all the tributaries were considered individually, they would form a large array of scenarios. The analysis of the field data indicates that there is a good correlation between salinity at various sites with the total freshwater flow volume to the Northwest Fork. The physical explanation for this correlation is the strong tidal mixing in the Northwest Fork. For example, when the tide rises, freshwater flows from Kitching Creek will be pushed upstream into the river reaches above the mouth of Kitching Creek and thus influence the salinity there. It is the total volume of fresh water entering the Northwest Fork that matters the most for the reaches between RM 6 and RM 9. The origin of fresh water (whether the fresh water was from Kitching Creek or some other tributary) does not seem to be an important factor in the current analysis. Such a finding has two implications:

1. Freshwater from all the tributaries affects the salinity in the Northwest Fork. Therefore, any increase of freshwater discharge from any combination of tributaries will help achieve the salinity management goal of the Northwest Fork between RM 6 and RM 9. In addition to increasing freshwater flows from the G-92, flows from other tributaries and basins such as Cypress Creek/Pal Mar, and Kitching Creek also should be fully utilized.
2. Salinity predictions in the Northwest Fork between RM 6 and RM 9 can be based on total freshwater flow to the Northwest Fork instead of freshwater flow from each individual tributary. Such an approach will allow the testing of more restoration scenarios with limited resources. This capability is especially critical in the initial alternative assessment phase of the restoration plan since numerous scenarios need to be analyzed. When the total amount of freshwater demand is determined, the analysis can then evolve into the next phase, that is, to consider the freshwater contribution from each tributary individually to meet the Northwest Fork freshwater demand. At that phase, a model with more refined spatial resolution, such as the RMA model that was described in the previous sections, can be used for scenarios where tributaries are simulated separately from each other.

The salinity value predicted by Equation [11] is tidally averaged salinity over a lunar tidal cycle. The actual salinity in the river constantly varies in response to tides. If the hourly salinity variation over each tidal cycle needs to be considered, then the information is available from the original model output.

Figure 6-22 is the model output of salinity at the Pennock Point seagrass transect (RM 2.44) in a lunar month. The graphs are the output under three freshwater flow conditions: 500 cfs, 800 cfs, and 1200 cfs. The amount of freshwater flow affects both the overall salinity level and the range of salinity variation (the difference of salinity between high tide and low tide).

Although **Figure 6-22** represents the salinity predictions for only one site under three flow conditions, the model simulation output included salinity for 20 sites under 12 different constant flow conditions; thus 240 sets of time-series data were produced. **Figure 6-22** represents one example from a large array of charts in the model output that cover a wide range of freshwater flows. The salinity conditions represented by 500, 800, and 1200 cfs are relatively high flows that begin to affect salinity conditions at the Pennock Point seagrass site.

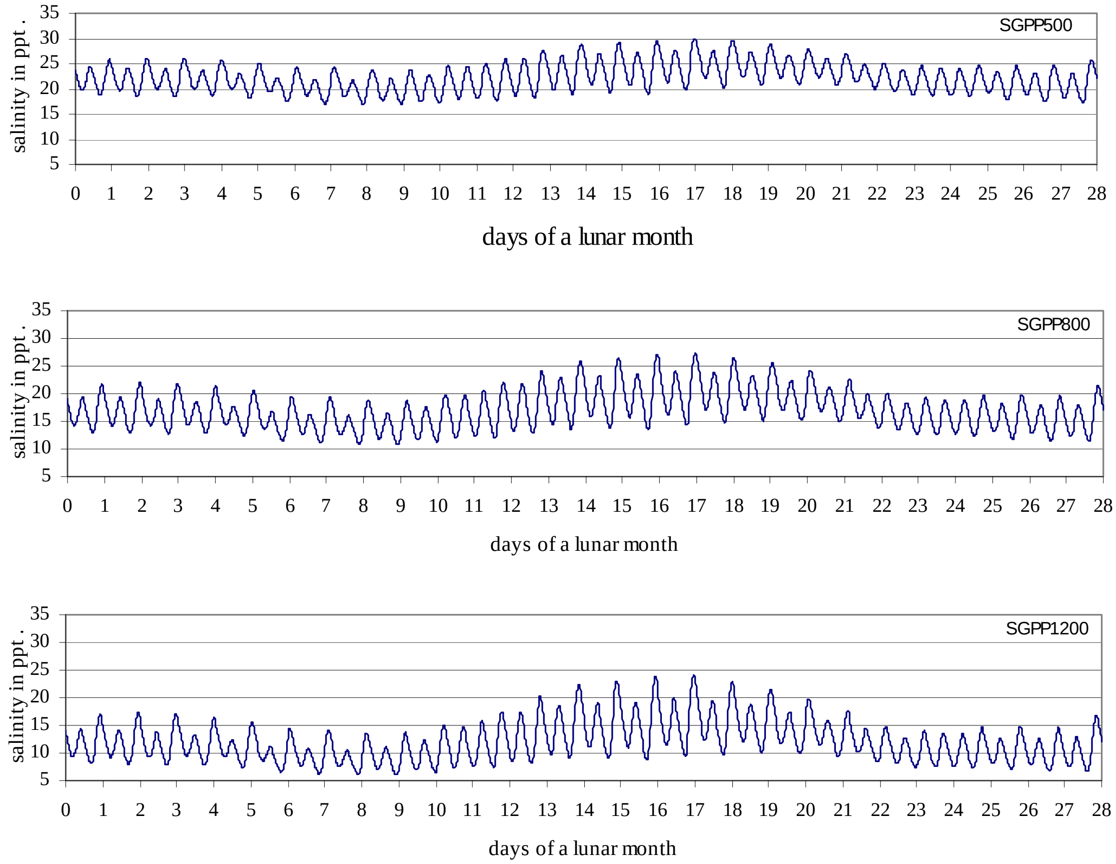

Figure 6-22. Salinity at Pennock Point Seagrass Transect (RM 2.44) in a Lunar Month; Total Freshwater Flow to the Loxahatchee River: 500, 800, and 1200 cfs.

The RMA was applied to scenarios with varying amounts of freshwater flow. Both the field data and model simulation indicated that there is a strong correlation between freshwater flow and the salinity regimen in the estuary. Based on model output and field data analysis, a relationship was established to predict salinity at various points in the estuary with respect to freshwater flow rates and tidal fluctuations. The salinity/freshwater relationship was applied in the Loxahatchee River MFL study (SFWMD 2002b). The RMA model was also used to provide a preliminary assessment of the impacts that inlet deepening and sea level rise have had on the salinity regime in the estuary (Hu 2002).

LONG-TERM SALINITY MANAGEMENT MODEL

The freshwater/salinity relationship described in the previous section was coded into the Loxahatchee Estuary Long-Term Salinity Management Model (LSMM) to predict tidally averaged salinity in response to various restoration scenarios. This model also can simulate system operation rules and calculate the amount of freshwater demand for salinity management.

The salinity values in **Table 6-14** are based on an equilibrium state with constant freshwater flows. In the applications of the freshwater input versus salinity relationships, the dynamic nature of the system needs to be considered. Under natural conditions, freshwater flow is rarely constant. The salinity conditions observed in the estuary are the result of a series of transitions from one state to the next. The changes in salinity lag behind the changes in freshwater flow. Following an increase of freshwater flow, salinity in the estuary will decrease accordingly and gradually approach a new equilibrium state. As the amount of freshwater decreases, the salinity in the estuary will increase gradually. Depending on the direction of salinity changes, the process can be described as an exponential increase or decay. **Figure 6-23** is a graphic description of salinity transition when an increase of freshwater flow occurs. The dotted line indicates the equilibrium salinity at the higher level of freshwater flow.

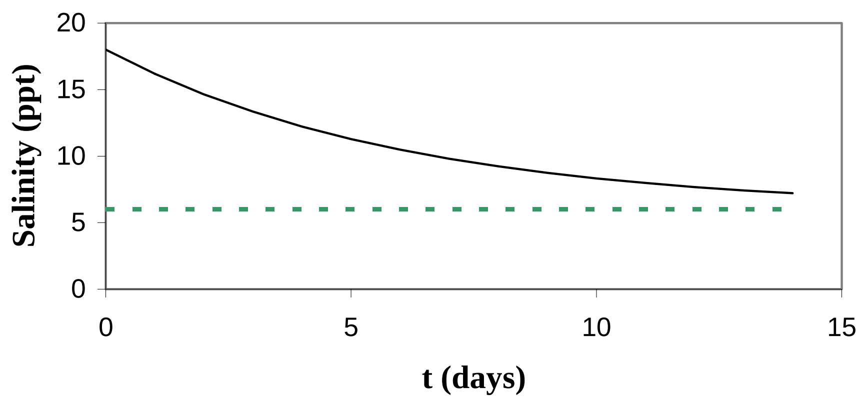

Figure 6-23. Salinity Regimen Transition Process.

The salinity condition within the estuary consists of a series of transitions from one quasi-equilibrium condition to another. This concept is reflected in the LSMM model. The LSMM calculates the potential target (equilibrium) salinity based on the amount of freshwater flow. It then calculates the salinity change on daily time steps using the following equation:

$$SAL2 = SALEQ + (SAL1-SALEQ)*Exp(-cT) \qquad [16]$$

where SAL1 is the salinity at the beginning of the time step, SAL2 is the salinity at the end of the time step, SALEQ is the equilibrium salinity for certain amount of freshwater flow after the transition has completed. T is time and c is a constant that determines the speed of transition. Apparently at the beginning of the time step (T=0), SAL2 = SAL1 and if the freshwater flow remains the same, SAL2 will eventually reach SALEQ.

Because freshwater flow is provided by the watershed (WaSh) model in daily time steps, the calculation of the Long-Term Salinity Management Model is carried at fixed 24-hour time steps.

The predicted salinity depends on both target (equilibrium) salinity and the initial salinity condition at the beginning of the time step. If the freshwater flow changes before the salinity transition is complete, then a new transition begins and the calculations are repeated under the new flow condition.

The LSMM is designed to assess daily average salinity over a long period of time. Because the program operates on daily time steps (versus minutes or seconds of a full hydrodynamic model), it allows the assessment of long-term data (39 years in this model simulation) at minimum cost and computing time. In addition to using hydrologic data provided by the WaSh model, the LSMM can also modify the hydrograph based on certain operational rules such as MFL criteria. The model also calculates the amount of freshwater demand for salinity management and nutrient loadings assuming a target concentration for flows.

Figures 6-24 through **6-27** depict the salinity calculations of the LSMM for December 2002 through April 2004 (517 days). The model output was compared with field data from four salinity stations in the Northwest Fork and the embayment area near the Jupiter Inlet. **Table 6-15** lists the salinity values of both the LSMM model prediction and field data. The mean salinity of LSMM model output is slightly higher than field data at the four stations by 0.1 ppt to 1.4 ppt. The modeled salinity values are likely higher than the field values because the flow gauges on the Northwest Fork and major tributaries do not monitor all of the fresh water entering the system. Thus the actual freshwater flows were higher than measured values resulting in lower actual recorded salinity values. **Tables 6-16** and **6-17** list the statistics of LSMM model prediction and field data for two relatively dry periods (March through May) and the rest of the year, respectively. In general, the simulated daily salinity statistically matches the observed salinities.

Table 6-15. Comparison of Salinity Values from the LSMM Model and Field Data: December .2002 to April 2004 (517 days).

Station ID	PD (RM1.77)		BD (RM 5.92)		KC (RM 8.13)		RM9	
Date Type	**Model**	**Field**	**Model**	**Field**	**Model**	**Field**	**Model**	**Field**
Maximum salinity (ppt)	34.7	35.5	21.8	20.2	7.6	7.6	2.9	4.4
Minimum salinity (ppt)	25.0	22.4	1.1	0.2	0.1	0.1	0.0	0.1
Mean salinity (ppt)	32.1	31.8	11.1	9.7	2.1	1.5	0.6	0.5
Median salinity (ppt)	33.1	32.4	12.5	10.1	1.8	0.7	0.4	0.3
Standard Deviation (ppt)	2.40	2.50	6.22	5.49	1.94	1.71	0.62	0.58
Data Count	517	477	517	502	517	506	517	199
Number of Missing Records	0	40	0	15	0	11	0	318

Table 6-16. Comparison of Dry Season Salinity Values from the LSMM Model and Field Data: March through May 2003 and March through April 2004 (153 days).

Station ID	PD (RM 1.77)		BD (RM 5.92)		KC (RM 8.13)		RM9	
Date Type	Model	Field	Model	Field	Model	Field	Model	Field
Maximum salinity (ppt)	34.7	35.5	21.8	20.2	7.6	7.6	2.9	4.4
Minimum salinity (ppt)	26.2	30.1	3.4	0.3	0.5	0.2	0.2	0.3
Mean salinity (ppt)	33.5	33.7	15.9	12.3	3.6	2.5	1.0	1.0
Median salinity (ppt)	33.8	33.9	15.9	13.1	3.1	1.7	0.7	0.5
Standard Deviation (ppt)	1.40	1.19	3.98	4.97	2.04	2.08	0.78	0.87
Data Count	153	117	153	150	153	153	153	61
Number of Missing Records	0	36	0	3	0	0	0	92

Table 6-17. Comparison of Salinity Values from the LSMM Model and Field Data: December 2002 through February 2003 and June 2003 through February 2004 (364 days).

Station ID	PD (RM 1.77)		BD (RM 5.92)		KC (RM 8.13)		RM9	
Date Type	Model	Field	Model	Field	Model	Field	Model	Field
Maximum salinity (ppt)	34.5	35.1	20.3	19.6	6.0	6.9	2.0	0.8
Minimum salinity (ppt)	25.0	22.4	1.1	0.2	0.1	0.1	0.0	0.1
Mean salinity (ppt)	31.5	31.1	9.1	8.6	1.5	1.1	0.4	0.3
Median salinity (ppt)	32.2	31.7	7.9	8.6	0.7	0.3	0.2	0.3
Standard Deviation (ppt)	2.48	2.48	5.90	5.34	1.52	1.32	0.41	0.10
Data Count	364	360	364	352	364	353	364	138
Number of Missing Records	0	4	0	12	0	11	0	226

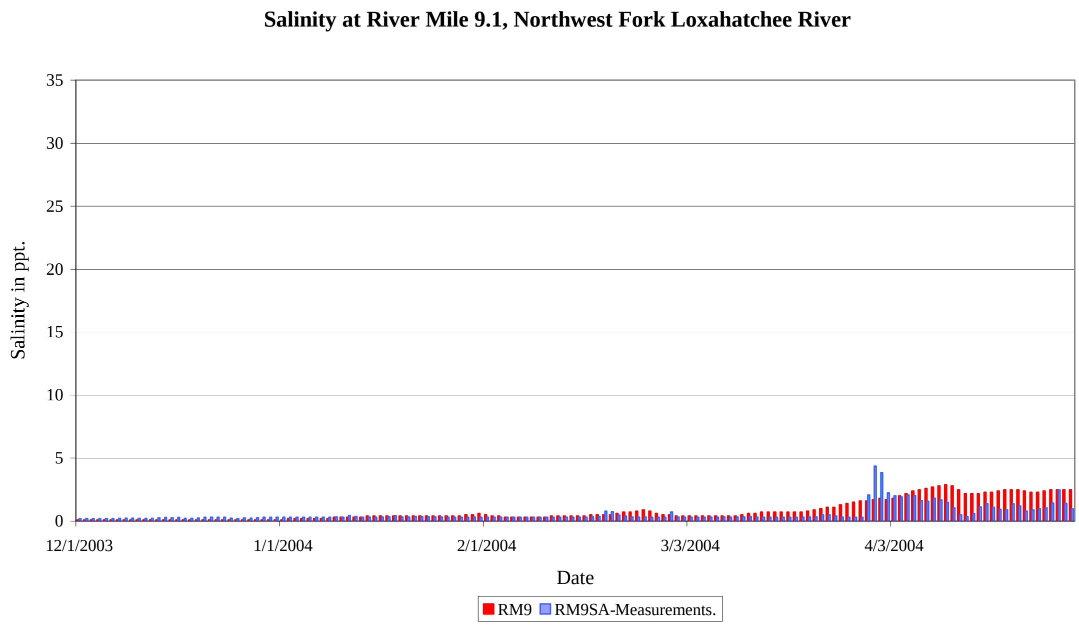

Figure 6-24. Field Measurements vs. LSMM Salinity Computation Results for RM 9.12.

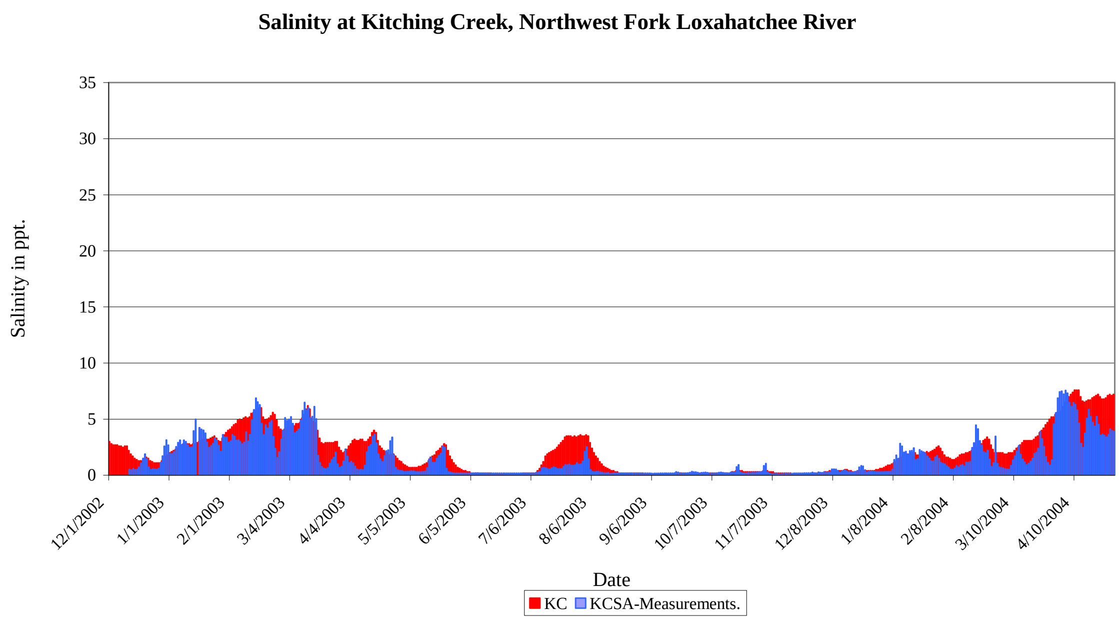

Figure 6-25. Field Measurements vs. LSMM Salinity Computation Results for Kitching Creek (RM 8.13).

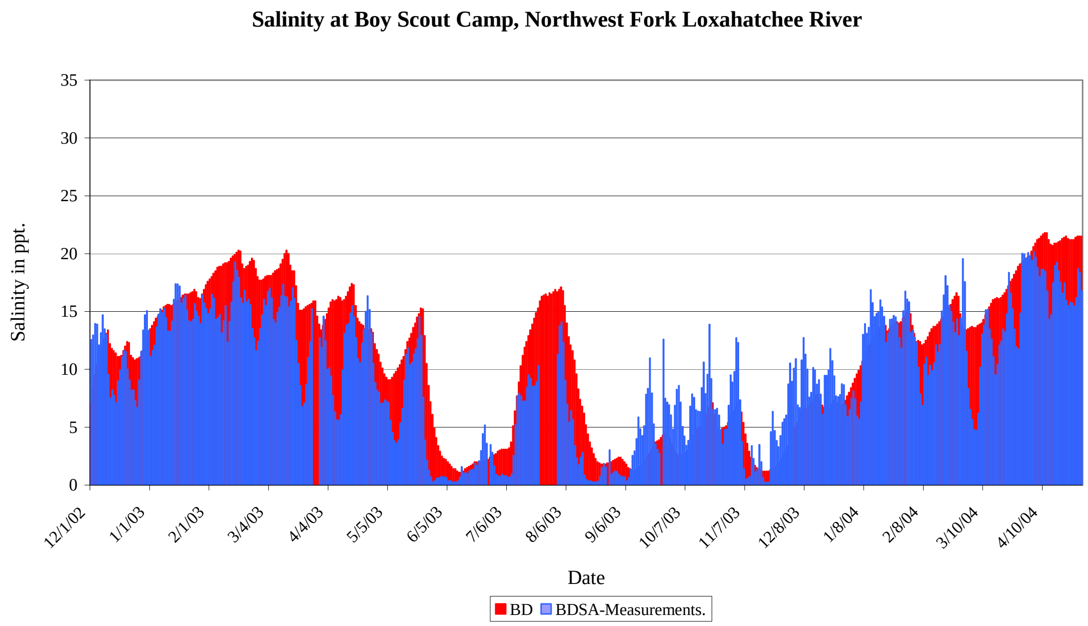

Figure 6-26. Field Measurements vs. LSMM Salinity Computation Results for Boy Scout Dock (RM 5.92).

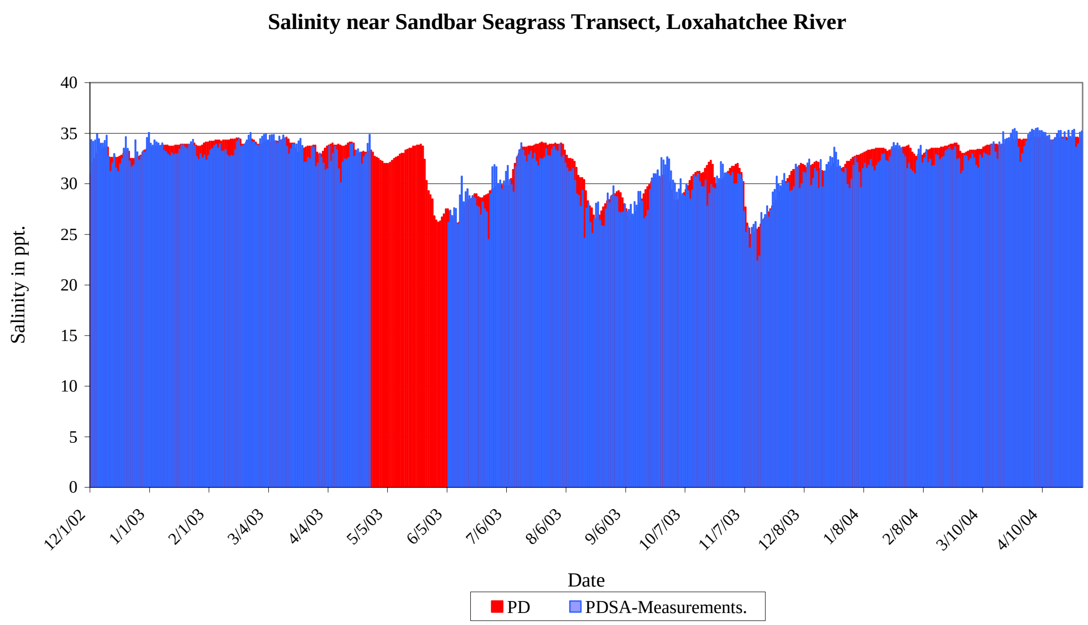

Figure 6-27. Field Measurements vs. LSMM Salinity Computation Results for Pompano Drive Embayment Area (RM 1.77).

SUMMARY

This chapter describes the hydrologic and salinity models applied in the Northwest Fork of the Loxahatchee River Restoration Plan. The Loxahatchee Watershed (WaSh) model was developed to simulate freshwater flow from each of the tributaries into the Northwest Fork. The WaSh model is based on restructuring HSPF (Hydrologic Simulation Program – Fortran) into a cell-based system with the addition of a groundwater model and a full dynamic channel routing model (Wan et al. 2003). The model is capable of simulating surface water and groundwater hydrology in watersheds with high groundwater tables and dense drainage canal networks. The WaSh model was calibrated and validated using long-term flow data collected at S-46, Lainhart Dam, Cypress Creek, Hobe Grove Ditch and Kitching Creek. The daily flow outputs from the 39-year simulation (1965–2003) provide the basis for the base condition and flow restoration scenarios of the Northwest Fork ecosystem restoration.

The Loxahatchee River Hydrodynamics/Salinity (RMA) model was developed to simulate the influence of freshwater flows on salinity conditions in the Loxahatchee River and Estuary. The RMA model is based on the RMA-2 and RMA-4 and was calibrated against field data from five locations and provided salinity predictions for many other sites where field data are not available. Tide/salinity data collected since 2002 have provided a field database for the investigation of the impact of freshwater flow on the salinity regime in the Northwest Fork.

A Long-Term Salinity Management Model (LSMM) was developed to predict long-term daily salinity and calculate several other performance parameters under various ecosystem restoration scenarios. Field data, regression analyses, and results from multidimensional hydrodynamic computer models were integrated into the LSMM as a system simulation and management tool. This salinity management model is applied to predict daily salinity from for the simulation period from 1965 to 2003 under the base condition and various restoration scenarios.

Salinity prediction and other computations were conducted using the Long-Term Salinity Management Model over the 39-year period. Such long-term simulations are required to investigate ecosystem response and assess the effectiveness of proposed restoration approach. The output of the Long-Term Salinity Management Model for six constant flow restoration scenarios is described in **Chapter 7.**

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Northwest Fork Ecosystems Constant Flow Restoration Scenario Evaluation

Initially, five constant flow restoration scenarios for the Northwest Fork ecosystem were developed and modeled. The evaluations of the results of the five constant flow scenarios are offered in this chapter. The modeling tools used for flow scenario evaluation are described in **Chapter 6**. The Loxahatchee Watershed Model (WaSh) simulated flow from all tributaries to the Northwest Fork. These included flows from the southern watershed areas that provide flows over Lainhart Dam, and flows from other tributary areas north of Lainhart Dam including Cypress Creek, Kitching Creek and Hobe Grove Ditch. To model realistic hydrologic conditions, the simulated flows were based on a 39-year period of record (POR) from 1965 to 2003. These data were used to establish the base condition for scenario evaluation. The Loxahatchee Long-term Salinity Management Model (LSMM) was then used to predict daily salinity under the five scenario conditions at 15 locations (**Figure 6-14**). The ecological benefits from the resulting flow and salinity conditions are evaluated with respect to each of the VECs described in **Chapter 4**. **Figure 7-1** provides an overview of the Northwest Fork restoration scenario evaluation process.

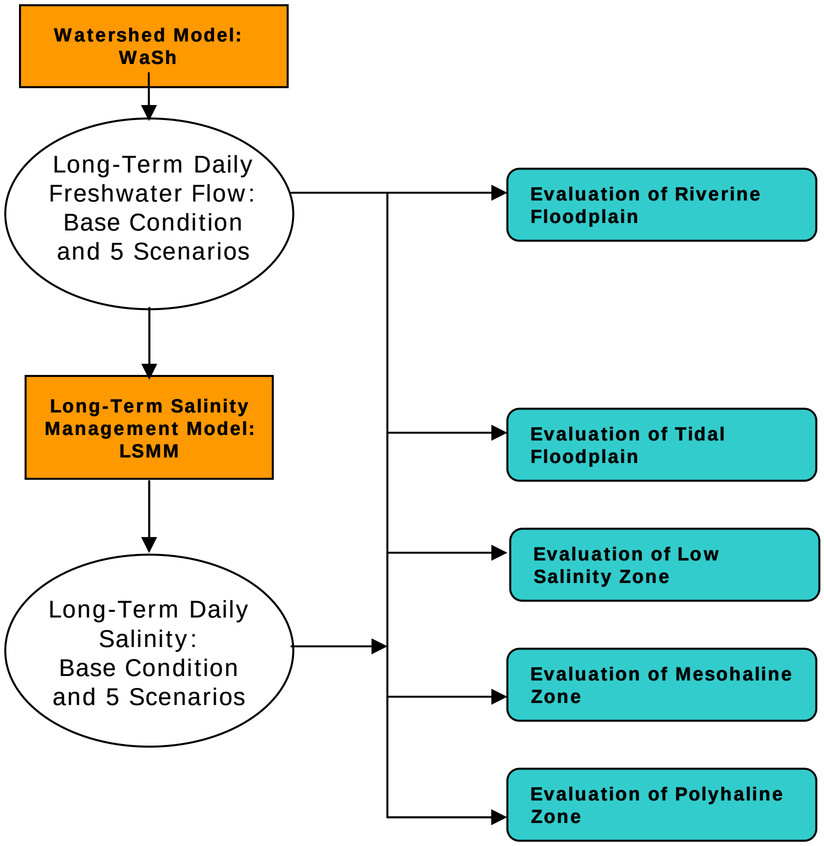


Figure 7-1. Flow Diagram of the Northwest Fork Ecosystem Restoration Flow Scenario Evaluation.

The five constant flow restoration scenarios were designed to represent different levels of flows from a tributary or a combination of tributaries to the Northwest Fork. The scenarios were selected based on information provided by members of the public and agency representatives at meetings held over the past several years to discuss the restoration of the Northwest Fork. For example, a flow of 65 cfs had been used as a flow target in the model for the development of the *Northern Palm Beach County Comprehensive Water Management Plan* (SFWMD, 2002). **Table 7-1** summarizes the flow component(s) of each scenario. The next section of this chapter describes and discusses the five constant flow scenarios in detail.

Table 7-1. Summary of the Northwest Fork of the Loxahatchee Constant Flow Restoration Scenarios.

Northwest Fork Tributaries	BASE condition	LD65	LD65TB65	LD90TB110	LD 200	LD200TB200
Lainhart Dam (LD)	39-year POR	65 cfs	65 cfs	90 cfs	200 cfs	200 cfs
Other tributaries (TB)[a]	39-year POR	39-year POR - 30 cfs	65 cfs	110 cfs	39-year POR – 30 cfs	200 cfs
Total Flow[b]	50 cfs	95 cfs	130 cfs	200 cfs	230 cfs	400 cfs

POR = Period of record.

[a] Other tributaries include Cypress Creek, Hobe Grove Ditch, and Kitching Creek.

[b] Total Flow for POR is approximated using the modeled time series data.

CONSTANT FLOW SCENARIOS

The **BASE** simulation represents the existing or current conditions of the Loxahatchee River Watershed and was modeled based on the 39-year POR from 1965 to 2003. Simulations of the five constant flow restoration scenarios were conducted with certain modifications to the **BASE** simulation hydrographs. The modifications represent scenarios that provide additional freshwater flows to the upper Northwest Fork at Lainhart Dam and from the tributaries (Cypress Creek, Hobe Grove, and Kitching Creek) to reduce salinity in the freshwater segments of the Northwest Fork. The results of each simulation are presented and followed with a summary of potential impacts to the previously described VEC species (riverine and tidal floodplains, larval fishes, oysters and seagrasses) in **Chapter 4**. Adult fish and other wildlife will be mentioned although their specific biological/hydrological requirements are unknown.

CONSTANT FLOW SIMULATIONS

Scenario 1: LD65

In this scenario, the hydrograph of **BASE** was modified by increasing flows at the Lainhart Dam. Whenever flow at Lainhart Dam was below 65 cfs under the BASE condition, water was added to raise the Lainhart Dam flow to 65 cfs. Therefore in this simulation, freshwater flow from the Lainhart Dam was never less than 65 cfs. In this simulation, no change was made to flows from the tributaries Cypress Creek, Hobe Grove, and Kitching Creek. Flow from these three tributaries was the same as the BASE case, which is cumulative total of 30 cfs.

With a constant flow of 65 cfs or greater at Lainhart Dam, this simulation located the saltwater front (>2 ppt) between RM 9.0 and the mouth of the Kitching Creek at RM 8.13.

Scenario 2: LD65TB65

In Scenario 2, the hydrograph of **BASE** was modified at both the Lainhart Dam and the tributaries. Whenever flow at Lainhart Dam was below 65 cfs, water was added to raise the Lainhart Dam flow to 65 cfs. Whenever total flow from the tributaries was below 65 cfs, water was added to raise the total flow from the tributaries to 65 cfs. Therefore in this simulation, freshwater flow from the Lainhart Dam was never less than 65 cfs, and total flow from the tributaries was never less than 65 cfs. The combined flow from both Lainhart Dam and the tributaries was 130 cfs in this simulation.

With the increased flows at both Lainhart Dam and the tributaries, this simulation located the saltwater front (>2 ppt) between the mouth of Kitching Creek (RM 8.13) and RM 8.0.

Scenario 3: LD90TB110

In Scenario 3, the hydrograph of **BASE** was modified at both Lainhart Dam and the tributaries. In this simulation, whenever flow at Lainhart Dam was below 90 cfs, water was added to raise the flow at Lainhart Dam to 90 cfs. Whenever total flow from the tributaries was below 110 cfs, water was added to raise the total flow from the tributaries to 110 cfs. Therefore, in this simulation, freshwater flow from the Lainhart Dam was never less than 90 cfs, and total flow from the tributaries was never less than 110 cfs. The combined flow from both Lainhart Dam and the tributaries was 200 cfs in this simulation.

With the increased flows at both Lainhart Dam and the tributaries, this simulation located the saltwater front (>2 ppt) between the mouth of Kitching Creek (RM 8.13) and Boy Scout Dock (RM 5.92).

Scenario 4: LD200

In Scenario 4, the hydrograph of **BASE** was modified at Lainhart Dam. Whenever flow at Lainhart Dam was below 200 cfs, water was added to raise the flow over Lainhart Dam to 200 cfs. Therefore, freshwater flow from the Lainhart Dam was never less than 200 cfs. In this simulation, no change was made to flows from the tributaries Cypress Creek, Hobe Grove, and Kitching Creek. Flow from these three tributaries was the same as the **BASE** case.

With the increased flow at Lainhart Dam, this simulation located the saltwater front (>2 ppt) between the mouth of Kitching Creek (RM 8.13) and Boy Scout Dock (RM 5.92).

Scenario 5: LD200TB200

In Scenario 5, the hydrograph of **BASE** was modified at both the Lainhart Dam and the tributaries. Whenever flow at Lainhart Dam was below 200 cfs, water was added to raise the Lainhart Dam flow to 200 cfs. Whenever total flow from the tributaries was below 200 cfs, water was added to raise the total flow from the tributaries to 200 cfs. Therefore, freshwater flow from the Lainhart Dam was never less than 200 cfs, and flow from the tributaries was never less than 200 cfs. The combined flow from both Lainhart Dam and the tributaries was 400 cfs in this simulation.

With the increased flows at both Lainhart Dam and the tributaries, this simulation located the saltwater front (>2 ppt) between River Mile 6.0 and Boy Scout Dock (RM 5.92). The flows and salinity conditions of the base and the five constant flow scenarios are summarized in **Table 7-2**.

Table 7-2. Long-Term Salinity Management Model Simulation of Five SConstant Flow Restoration Scenarios.

Scenario	Base Condition Hydrograph	Added Flows From Lainhart Dam	Added Flows From Tributaries	Total Added Flows	Approximate Saltwater Front Position
Base	1965-2003 base condition generated by watershed model	No additional flows	No additional flows	No additional flows from Lainhart Dam or tributaries	RM 9.5
LD65	1965-2003 base condition generated by watershed model	Water added as needed so flow is a minimum of 65 cfs at all times	No additional flows	Additional flows only from Lainhart Dam for a minimum of 65 cfs; No additional flows from tributaries	RM 8.5
LD65TB65	1965-2003 base condition generated by watershed model	Water added as needed so flow is a minimum of 65 cfs at all times	Water added as needed so flow is a minimum of 65 cfs at all times	Additional flows from Lainhart Dam and tributaries. Total flow is a minimum of 130 cfs at all times.	RM 8.0
LD90TB110	1965-2003 base condition generated by watershed model	Water added as needed so flow is a minimum of 90 cfs at all times	Water added as needed so flow is a minimum of 110 cfs at all times	Additional flows from Lainhart Dam and tributaries. Total flow is a minimum of 200 cfs at all times	RM 7.5
LD200	1965-2003 base condition generated by watershed model	Water added as needed so flow is a minimum of 200 cfs at all times	No additional flows	Additional flows only from Lainhart Dam for a minimum of 200 cfs; No additional flows from tributaries	RM 7.0
LD200TB200	1965-2003 base condition generated by watershed model	Water added as needed so flow is a minimum of 200 cfs at all times	Water added as needed so flow is a minimum of 200 cfs at all times	Additional flows from Lainhart Dam and tributaries. Total flow is a minimum of 400 cfs at all times	RM 6.0

SALINITY SIMULATIONS

The salinity values for each constant flow simulation scenario was averaged over the entire 39-year POR to provide an overview of differences in salinity between the scenarios. **Table 7-3** lists the average salinity for the 15 salinity study sites (**Chapter 6, Figure 6-14**).

Table 7-3. Average Salinity (in ppt) at 15 Salinity Study Sites for the Constant Flow Restoration Scenarios Over the 39-Year Simulation Period.

Salinity Study Site[a]		Constant Flow Restoration Scenarios					
Site ID	River Mile	BASE	LD65	LD65TB65	LD90TB110	LD200	LD200TB200
CG	0.70	33.0	32.8	32.6	32.2	31.8	30.7
SGNB	1.48	32.0	31.6	31.3	30.4	29.6	27.6
SGSB	1.74	31.3	30.8	30.3	29.3	28.4	26.0
PD	1.77	31.2	30.6	30.2	29.2	28.3	25.8
SGPP	2.44	29.2	28.5	27.9	26.5	25.2	22.0
O1	2.70	26.9	26.1	25.4	23.7	22.3	18.7
O2	3.26	24.6	23.5	22.5	20.4	18.7	14.5
O3	3.74	22.5	21.0	19.9	17.4	15.5	11.0
O4	4.13	21.0	19.4	18.1	15.4	13.4	8.9
O5	4.93	16.2	13.9	12.2	9.1	7.2	3.5
O6	5.45	13.5	10.7	8.9	5.9	4.3	1.6
BD	5.92	10.9	7.9	6.2	3.7	2.5	0.7
VT9	7.06	5.8	3.0	1.8	0.7	0.4	0.2
KC	8.13	2.7	0.8	0.4	0.2	0.1	0.1
RM9	9.12	1.0	0.2	0.1	0.1	0.1	0.1

[a] Additional study site information is presented in **Chapter 6, Table 6-8.**

Table 7-3 presents the salinity gradient of each scenario for the 15 study sites. Salinity ranges from near ocean conditions at the U.S. Coast Guard Station (RM 0.7; CG) near Jupiter Inlet to freshwater conditions at River Mile 9 (RM 9.12) in the Northwest Fork of the Loxahatchee River. The five scenarios that increase freshwater flows also lower the salinity throughout the river and the estuary.

It is important to point out that the salinity condition in the Northwest Fork is extremely sensitive to the amount of freshwater flow. A small change in freshwater flow of less than 10 cfs can cause changes in salinity as high as several ppt in the upper Northwest Fork. **Table 7-3** only provides the average salinity for each site. A complete assessment of the salinity condition under each scenario is provided in greater detail in the following sections.

ECOLOGICAL EVALUATION OF CONSTANT FLOW SCENARIOS

EVALUATION OF RIVERINE FLOODPLAIN

Evaluation Methods

With the establishment of river flow and stage relationships (**Chapter 5**), it is possible to evaluate predicted floodplain inundation characteristics on the riverine freshwater floodplain reach of the Northwest Fork. **Figures 7-2** and **7-3** illustrate the relationship between flows over Lainhart Dam and river stage levels at Transect #1 (RM 14.50) and Transect #3 (RM 12.07). The range and average ground elevations for hydric hammock and swamp forest types were determined from transect vegetation and survey data. In Transect #3 the distribution of hydric hammock community was not surveyed, and thus only floodplain swamp elevations are shown in **Figure 7-3**.

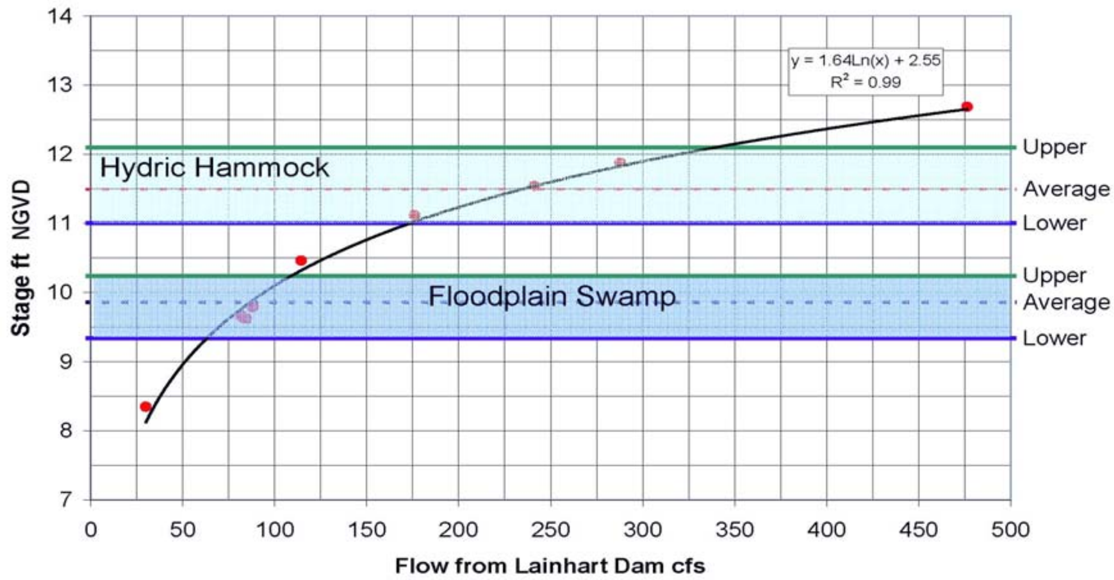


Figure 7-2. The Relationship of Surface Water Stage and Flow over Lainhart Dam at Transect #1.

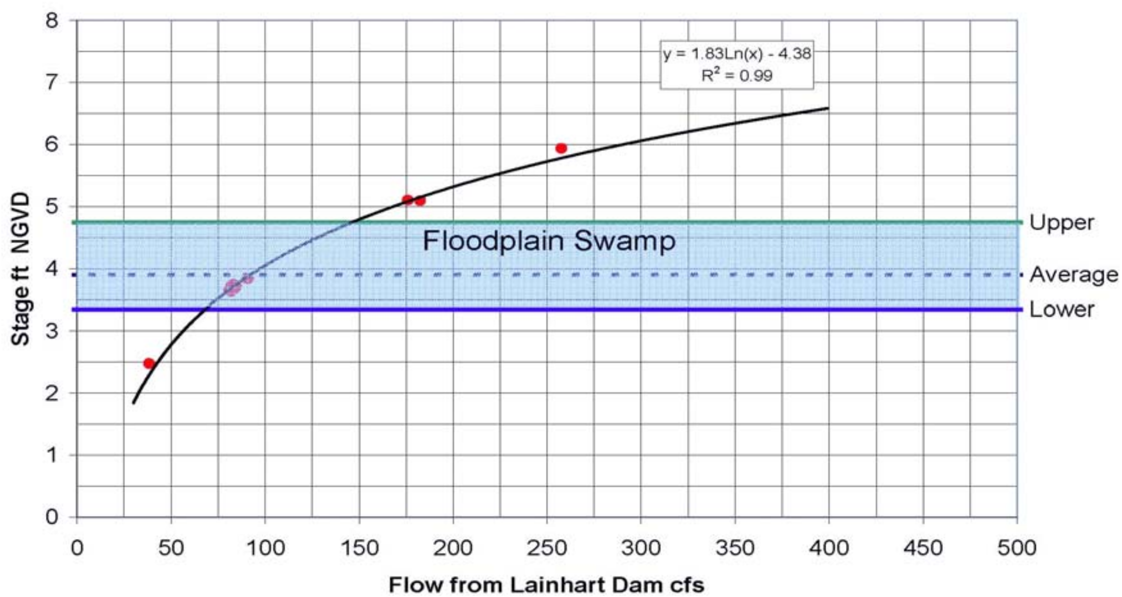


Figure 7-3. The Relationship of Surface Water Stage and Flow over Lainhart Dam at Transect #3.

Figures 7-4 and **7-5** show the approximate surface water stages at Transect #1 (RM 14.50) and Transect #3 (RM 12.07), respectively, for five Lainhart Dam flows. The transect profiles are shown to illustrate the variable topography along each of the two transects and to illustrate the average ground elevation of hydric hammock and swamp communities. At 65 cfs (solid blue line), the river stage at Transect #1 corresponds to the bottom elevation of the swamp community, and at Transect #3 this line is at the bottom elevations of most of the swamp community, and flow is contained within the banks of the river. At 90 cfs (dashed orange line), the river stage at Transect #1 and Transect #3 is at the average elevation of the swamp community, and flow is still contained within the banks of the river. At 110 cfs (dashed blue line) the flow is out of its banks at Transect #1 and the floodplain is inundated to the upper level of the swamp community; at Transect #3 the flow is in the banks within the main channel and out of the bank of the braided channel in the swamp area. At 180 cfs (dashed green line) the river stage is at the lower elevation of the hydric hammock community. At flows of 340 cfs (dashed green line) the river stage at is at the upper elevation of the hydric hammock community.

The **BASE** Case and five scenarios were evaluated with performance measures defined in **Chapter 4** to determine the impact on vegetation from the hydroperiods associated with each scenario. To evaluate the dry season performance in the riverine freshwater floodplain reach of the Northwest Fork, the **BASE** condition and the five constant flow scenarios were examined for monthly average flow conditions within the 39-year modeled dataset. For the analysis, the months of December through May, inclusive, were considered the dry season, whereas the months of June through November, inclusive, were considered the wet season.

To evaluate the performance in the wet season for each scenario on floodplain swamp communities, the total number of days was counted where the 20-day rolling average flow of 110 cfs was exceeded. A 20-day moving average is used to reflect the days after a storm when the flow in the river is lower than 110 cfs but the swamp may remain inundated by water ponded in the low areas. To examine the performance of wet season flows for each scenario for hydric hammock, the 39-year modeled dataset was used to establish days of inundation. The number of days of inundation was counted if the flow was greater than 180 cfs, 240 cfs, and 340 cfs, which correspond to the low, median and high elevation occurrences of hydric hammock at Transects #1.

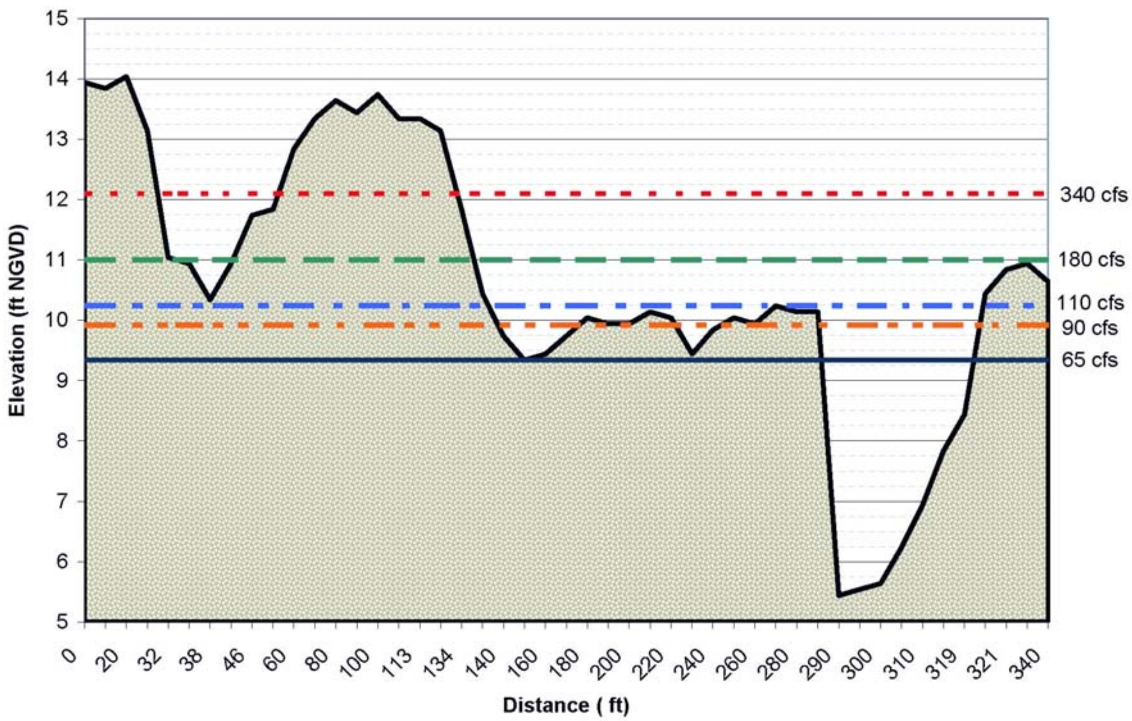


Figure 7-4. Surface Water Stage at Transect #1 and Corresponding Flows Over Lainhart Dam.

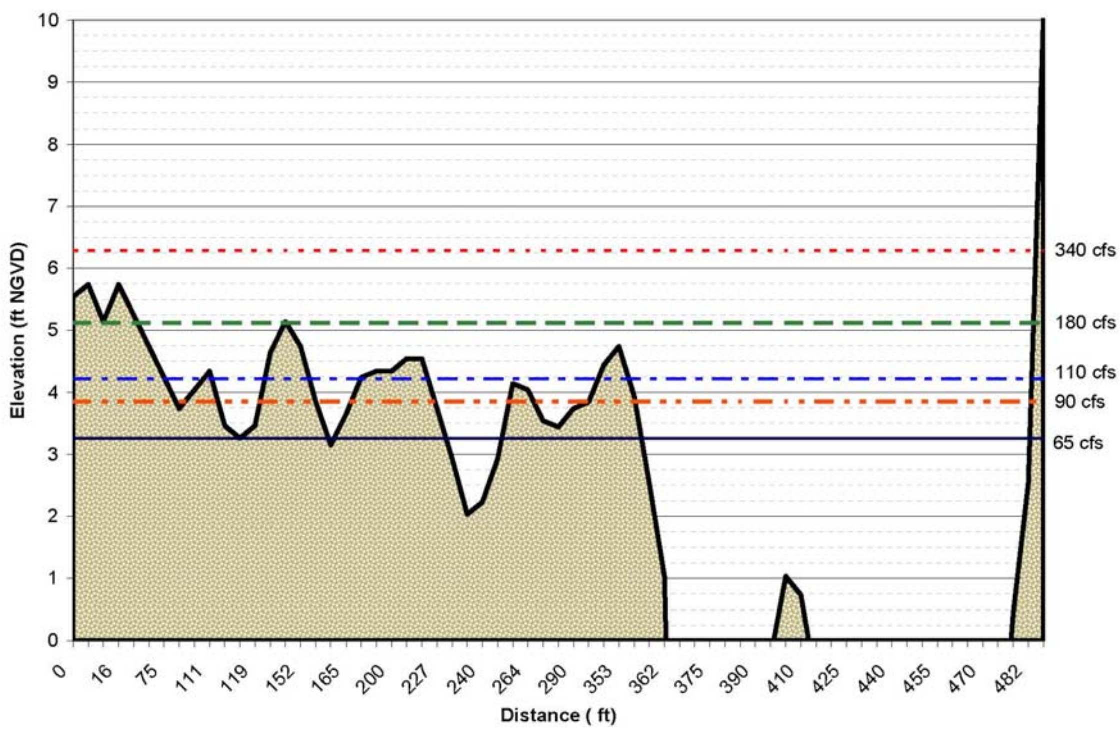


Figure 7-5. Surface Water Stage Across Transect #3 and Corresponding Flows Over Lainhart Dam.

Results and Discussion

Dry Season Evaluation

A monthly mean was determined for each month of the year and a yearly mean was determined for each year. The results are shown in **Tables 7-4** through **7-7**. Color codes were used to identify monthly average flow between 0-35 cfs (red), and 35-65 cfs (orange). Dry season flows were also evaluated for unseasonably high contributions to the Northwest Fork. The months highlighted in dark blue indicate the mean monthly flow was greater than 90 cfs during the dry season.

The **BASE** condition shows a large percentage of months when the mean monthly flows were below 35 cfs during the dry season (December to May) (**Table 7-4**). For the dry seasons of 1989 and 1990, mean monthly flows ranged from 2 to 16 cfs which may represent a stressed condition. The lowest average yearly flows occurred in 1989 (25 cfs), 1965 (34 cfs) and 1990 (36 cfs) while the highest average yearly flows occurred in 1995 (166 cfs), 1994 (165 cfs), and 1993 (150 cfs). The years 1970 and 1993 exhibited the highest dry season flows (highlighted in dark blue) with mean monthly flows ranging from 92 cfs to 237 cfs. The average dry season flow for the 39-year period was 66 cfs. High flows during the dry season would not harm the swamp communities but may impact deciduous seed germination and seedling/sapling growth, which is needed periodically to encourage new recruits to the communities. Also, the table illustrates how a lack of rain during the wet season can add to the low flow conditions on the Northwest Fork (i.e., 1988-1989).

Table 7-4. Examination of Flow of the **BASE** Condition for the 39-Year Modeled Dataset Using Mean Monthly Flows (cfs).

Dry Season	
<	35
<	65
>= 65 & <=90	
>	90

Wet Season	
<	35
<	65
>=	65

LNHRT-Base

	Date												
Years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
1965	39	35	14	2	1	14	29	45	10	136	71	10	34
1966	90	76	34	22	53	211	220	127	88	203	63	37	102
1967	22	40	37	18	5	52	89	114	67	193	79	26	62
1968	14	13	7	2	19	302	173	136	197	274	147	62	112
1969	71	45	116	35	154	120	79	131	135	269	173	86	119
1970	113	104	208	237	97	155	112	64	56	71	29	18	105
1971	16	18	12	3	47	19	38	46	136	79	194	73	57
1972	44	39	21	41	191	204	85	50	33	33	68	28	70
1973	28	36	14	9	13	80	66	124	134	168	41	39	63
1974	150	39	45	14	8	131	151	156	54	134	57	63	84
1975	27	30	20	7	33	104	141	31	85	108	39	15	54
1976	9	20	27	5	106	114	30	67	182	72	72	28	61
1977	60	19	10	2	25	33	11	24	271	42	24	139	55
1978	72	30	32	6	14	145	140	145	88	168	263	190	108
1979	193	79	56	47	61	51	31	19	161	146	113	66	85
1980	47	58	39	20	33	29	86	34	32	80	26	17	42
1981	7	9	3	1	2	6	6	152	176	46	53	9	39
1982	12	26	150	200	166	241	124	93	110	145	302	182	146
1983	143	200	172	108	76	141	77	135	268	342	198	157	168
1984	123	86	127	84	102	124	65	48	179	120	196	150	117
1985	72	43	28	61	21	25	65	40	144	110	53	71	61
1986	125	42	102	82	14	93	112	72	76	80	92	99	83
1987	112	36	69	25	15	24	43	30	39	137	234	34	67
1988	57	47	42	14	29	91	116	184	75	18	14	7	58
1989	4	2	17	8	7	8	30	85	25	79	14	15	25
1990	11	6	7	10	7	15	17	77	93	151	22	16	36
1991	142	118	53	141	119	160	128	86	134	192	92	83	121
1992	49	117	66	56	20	122	125	188	217	164	198	95	118
1993	231	204	200	122	92	104	87	85	164	281	149	89	150
1994	96	142	84	82	70	143	114	223	273	209	278	285	166
1995	140	96	98	85	69	101	131	288	186	352	271	153	165
1996	82	73	156	116	137	140	176	96	128	163	123	78	123
1997	81	104	84	121	93	214	109	200	222	105	83	149	130
1998	148	204	161	88	106	53	84	66	208	133	289	102	136
1999	227	89	70	39	30	172	122	109	198	335	206	109	142
2000	81	74	62	91	34	19	40	18	52	174	29	23	58
2001	16	9	46	24	8	43	197	260	254	236	145	78	110
2002	69	125	60	44	15	116	185	57	40	51	43	36	70
2003	22	14	62	46	119	137	48	149	90	73	146	75	82
Average	78	65	67	54	57	104	94	104	130	151	120	77	92

In the **LD65** scenario, dry season monthly flows were improved (greater than 65 cfs and less than 90 cfs) (**Table 7-5**). **LD65TB65** scenario used the same Lainhart Dam flows as the **LD65** scenario (see **Table 7-2)**; therefore, the **LD65TB65** figure was not included. Similar to the base condition, 20 percent (8 of 39 years) had more than 3 months of average monthly flow greater than 90 cfs (dark blue).

Table 7-5. Examination of Flow Conditions of the **LD65** Scenario for the 39-Year Modeled Dataset Using Mean Monthly Flows (cfs).

Dry Season		Wet Season	
<	35	<	35
<	65	<	65
>= 65 & <=90		>=	65
>	90		

LNHRT-LD65

	Date												
Years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
1965	65	70	66	65	65	66	71	79	65	160	96	65	78
1966	101	107	68	67	88	211	220	133	95	203	72	65	119
1967	65	72	71	65	65	78	109	125	81	194	92	65	90
1968	65	65	65	65	67	303	174	137	200	274	147	68	136
1969	79	67	123	65	157	121	88	134	138	269	173	86	126
1970	113	104	209	237	102	155	112	70	75	77	65	65	115
1971	65	65	65	65	87	67	69	71	143	97	196	95	90
1972	66	66	66	72	193	204	87	72	65	65	86	65	92
1973	66	68	65	65	65	97	96	125	134	170	67	66	91
1974	162	65	75	65	65	136	151	156	69	135	80	70	103
1975	65	65	65	65	70	109	141	65	106	113	65	65	83
1976	65	72	67	65	132	118	65	94	182	85	91	66	92
1977	85	65	65	65	77	68	65	69	271	72	68	142	93
1978	89	65	67	65	66	161	140	147	89	168	263	190	126
1979	193	79	67	79	74	71	65	65	170	149	116	75	100
1980	76	74	68	65	77	65	99	66	69	100	65	65	74
1981	65	65	65	65	65	65	65	177	176	70	79	65	85
1982	65	66	162	200	172	241	124	93	125	145	302	182	156
1983	143	200	172	108	76	141	77	135	268	342	198	157	168
1984	123	86	127	84	106	124	69	67	186	120	197	150	120
1985	73	65	65	85	65	71	80	70	157	112	68	85	83
1986	133	66	116	100	65	117	113	77	85	101	94	105	98
1987	114	65	87	65	65	70	77	67	75	150	234	65	95
1988	74	68	70	65	71	107	127	193	89	65	65	65	88
1989	65	65	65	65	65	65	67	100	65	99	65	65	71
1990	65	65	65	65	66	67	65	93	113	157	65	65	79
1991	161	124	77	141	125	160	128	93	134	192	93	84	126
1992	65	121	77	75	65	143	127	189	217	164	198	95	128
1993	231	204	200	122	92	104	87	86	164	281	149	89	150
1994	96	142	84	88	75	144	114	223	273	209	278	285	167
1995	140	96	98	85	70	102	131	288	186	352	271	153	165
1996	82	73	156	116	137	140	176	96	128	163	123	78	123
1997	81	104	84	123	94	214	109	200	222	105	83	149	131
1998	148	204	161	88	108	71	92	73	209	133	289	102	139
1999	227	89	71	65	65	178	123	112	198	335	206	109	148
2000	81	74	68	99	66	65	68	65	83	179	66	65	82
2001	65	65	83	66	65	86	198	260	254	236	145	78	134
2002	71	126	70	73	65	132	185	73	68	73	67	65	89
2003	65	65	85	70	140	137	68	149	93	81	147	76	98
Average	99	89	92	86	88	122	108	118	142	159	134	96	111

However, the mean monthly flows for the **LD90TB110** scenario (**Table 7-6**) have 23 of 39 years (59%) that had more than 3 months of average monthly flow greater than 90 cfs (dark blue).

Table 7-6. Examination of Flow Conditions of the **LD90TB110** Scenario for the 39-Year Modeled Dataset Using Mean Monthly Flows (cfs).

Dry Season		Wet Season	
<	35	<	35
<	65	<	65
>= 65 & <=90		>=	65
>	90		

LNHRT-LD90TB110

	Date												
Years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
1965	90	92	90	90	90	90	93	99	90	171	114	90	100
1966	115	126	91	90	106	212	220	143	105	204	91	90	133
1967	90	93	94	90	90	98	126	136	101	198	107	90	110
1968	90	90	90	90	91	304	178	142	206	274	148	90	149
1969	97	91	136	90	161	126	105	144	147	269	173	93	136
1970	122	112	216	237	117	157	118	91	97	96	90	90	128
1971	90	90	90	90	107	91	91	92	151	112	200	113	110
1972	90	90	90	94	197	204	100	93	90	90	104	90	111
1973	90	91	90	90	90	113	113	131	138	177	90	90	109
1974	173	90	96	90	90	144	152	159	91	144	101	91	119
1975	90	90	90	90	92	120	145	90	120	123	90	90	103
1976	90	95	90	90	143	127	90	109	184	103	109	90	110
1977	103	90	90	90	98	90	90	91	271	92	91	149	112
1978	108	90	91	90	90	173	144	155	99	168	263	190	139
1979	193	92	90	100	94	92	90	90	176	155	126	94	116
1980	97	96	91	90	98	90	113	90	92	116	90	90	96
1981	90	90	90	90	90	90	90	189	176	91	98	90	106
1982	90	90	173	203	180	241	125	100	143	146	302	182	164
1983	143	200	172	109	92	143	93	142	268	342	198	157	171
1984	124	91	131	94	125	128	90	91	197	125	209	153	130
1985	91	90	90	104	90	93	99	92	170	120	90	104	103
1986	144	90	133	115	90	129	121	94	101	115	105	122	113
1987	123	90	106	90	90	92	96	91	96	160	234	90	113
1988	94	90	92	90	93	121	138	202	103	90	90	90	108
1989	90	90	90	90	90	90	91	114	90	115	90	90	94
1990	90	90	90	90	90	91	90	106	129	164	90	90	101
1991	173	136	97	144	138	161	131	107	136	192	103	96	135
1992	90	130	95	96	90	158	135	191	217	166	199	99	139
1993	231	204	201	124	101	107	94	102	164	281	149	94	154
1994	99	142	92	105	92	146	121	223	273	209	278	285	172
1995	140	96	101	95	90	116	133	288	186	352	271	154	169
1996	91	90	163	126	148	140	177	105	134	163	127	92	130
1997	95	111	94	133	103	214	110	200	222	108	91	149	136
1998	149	204	161	96	121	93	105	93	213	133	289	103	146
1999	227	94	90	90	90	183	130	121	198	335	206	111	157
2000	92	90	91	115	90	90	92	90	102	186	90	90	102
2001	90	90	101	90	90	108	203	260	257	236	146	92	147
2002	90	133	90	95	90	144	188	93	91	95	91	90	107
2003	90	90	102	91	156	140	90	149	106	98	154	92	113
Average	114	106	109	105	107	135	121	131	152	167	146	111	125

The **LD200** (included as **Table 7-7**) and **LD200TB200** scenarios showed 100% inundation during the dry season. Vegetation reproduction in the swamp communities may be impacted by prolonged flooding. Additionally, flooding will present a problem in the lower segments of the hydric hammock and bottomland hardwood communities, which may cause significant declines in the target species in these communities. The **LD200TB200** scenario provides a 200 cfs flow from Lainhart Dam and an additional 200 cfs in the riverine reach for a total flow of 400 cfs in the tidal reaches of the river. High flow conditions may produce higher flow velocities which in turn may increase scouring of the banks, increase the depth of the channel, and increase turbidity levels in the main river channel downstream of the tidal reaches of the Northwest Fork. Changes in the width of the river channel were evident in historical aerial photographs that were examined for 1940 and 1995 (SFWMD 2002b). The tidal Northwest Fork is now much wider than it appeared in 1940.

The scenarios were not analyzed for all fish and wildlife impacts. The necessity for base line information on these ecological communities is addressed in **Chapter 10**. Data are needed on the general distribution, abundance, and reproductive cycles of native amphibians and floodplain fish species. These data will establish correlations between wet and dry season hydrological conditions and distribution and abundance of species for the Northwest Fork of the Loxahatchee River.

Table 7-7. Examination of Flow Conditions of the **LD200** Scenario for the 39-Year Modeled Dataset Using Mean Monthly Flows (cfs).

Dry Season	Wet Season
< 35	< 35
< 65	< 65
>= 65 & <=90	>= 65
> 90	

LNHRT-LD200

	Date												
Years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
1965	200	200	200	200	200	200	200	200	200	233	209	200	204
1966	205	214	200	200	200	242	248	213	200	243	200	200	214
1967	200	200	200	200	200	200	211	209	200	244	200	200	205
1968	200	200	200	200	200	309	226	215	253	274	206	200	224
1969	200	200	219	200	215	203	200	217	214	285	217	200	214
1970	209	201	274	258	204	219	207	200	201	200	200	200	214
1971	200	200	200	200	202	200	200	200	213	200	249	208	206
1972	200	200	200	200	241	237	200	200	200	200	201	200	207
1973	200	200	200	200	200	203	202	205	204	232	200	200	204
1974	244	200	200	200	200	208	201	219	200	220	200	200	208
1975	200	200	200	200	200	203	204	200	205	205	200	200	201
1976	200	200	200	200	215	202	200	201	233	200	205	200	205
1977	202	200	200	200	200	200	200	200	282	200	200	212	208
1978	203	200	200	200	200	239	204	221	200	218	276	233	216
1979	224	200	200	200	200	200	200	200	227	228	211	200	208
1980	200	200	200	200	200	200	203	200	200	206	200	200	201
1981	200	200	200	200	200	200	200	246	217	200	201	200	205
1982	200	200	244	239	236	252	204	200	223	215	307	206	227
1983	206	241	217	201	200	221	200	206	295	342	227	217	231
1984	209	200	214	200	219	207	200	200	260	204	281	218	218
1985	200	200	200	202	200	200	201	200	235	200	200	202	203
1986	223	200	220	203	200	204	202	200	200	203	200	209	205
1987	207	200	203	200	200	200	200	200	200	230	261	200	208
1988	200	200	200	200	200	204	218	247	200	200	200	200	206
1989	200	200	200	200	200	200	200	201	200	207	200	200	201
1990	200	200	200	200	200	200	200	200	216	218	200	200	203
1991	246	218	200	207	215	210	202	201	202	234	201	200	211
1992	200	204	200	200	200	241	213	242	241	220	240	200	217
1993	260	223	253	203	200	200	200	202	208	282	211	200	220
1994	200	211	200	200	200	207	204	243	300	236	307	294	233
1995	205	200	201	200	200	206	202	307	232	375	271	203	234
1996	200	200	230	207	219	204	234	200	213	218	213	200	212
1997	200	203	200	216	200	242	200	227	247	200	200	223	213
1998	223	240	217	201	212	200	201	200	262	203	306	200	222
1999	258	200	200	200	200	223	209	200	224	351	235	205	226
2000	200	200	200	208	200	200	200	200	200	249	200	200	205
2001	200	200	201	200	200	207	246	276	291	242	218	200	223
2002	200	210	200	200	200	219	233	200	200	200	200	200	205
2003	200	200	200	200	234	203	200	207	200	200	229	200	206
Average	208	204	207	204	205	213	207	213	223	231	223	206	212

Wet Season Evaluation

Tables 7-8, 7-9, 7-10, and **7-11** show the number of days with a 20-day moving average flow over Lainhart Dam greater than 110 cfs (which represents inundation). Months with flows greater than 110 cfs for 20 days or more are considered to be an inundation month and are highlighted in green. Those years with at least 120 days (4 or more months) of flows greater than 110 cfs are highlighted in dark green in the Grand Total column and would be considered optimum conditions. Those years with less than 4 months of flows greater than 110 cfs are considered a dry years.

Table 7-8. Floodplain Swamp Inundation Analysis for **BASE** Condition: Number of Days in a Month with 20-Day Moving Average Flows Greater Than 110 cfs.

Base Flow over 110

	Date													Months with
Years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Grand Total	over 20 days
1965	0	0	0	0	0	0	0	0	0	12	16	0	28	0
1966	4	0	8	0	0	23	31	27	0	22	11	0	126	4
1967	0	0	0	0	0	0	18	15	0	24	18	0	75	1
1968	0	0	0	0	0	25	31	27	18	31	30	1	163	5
1969	0	0	18	0	22	21	11	16	17	31	30	5	171	4
1970	14	23	19	30	9	30	20	0	0	0	0	0	145	4
1971	0	0	0	0	0	0	0	0	18	2	29	1	50	1
1972	0	0	0	0	18	30	11	0	0	0	0	0	59	1
1973	0	0	0	0	0	2	0	26	28	29	5	0	90	3
1974	15	8	0	0	0	13	31	31	1	21	0	0	120	3
1975	0	0	0	0	0	11	24	9	1	19	0	0	64	1
1976	0	0	0	0	4	21	0	0	26	7	0	0	58	2
1977	0	0	0	0	0	0	0	0	26	13	0	16	55	1
1978	5	0	0	0	0	6	31	26	0	20	30	31	149	5
1979	31	13	0	0	0	0	0	0	14	31	22	3	114	3
1980	0	0	0	0	0	0	0	0	0	4	0	0	4	0
1981	0	0	0	0	0	0	0	11	30	14	0	0	55	1
1982	0	0	16	30	25	30	26	0	3	27	29	31	217	7
1983	31	28	31	28	1	21	1	9	30	31	30	31	272	9
1984	23	0	8	14	1	23	0	0	10	24	8	28	139	4
1985	0	0	0	0	0	0	0	0	10	19	0	0	29	0
1986	20	0	3	19	0	5	16	12	0	0	9	1	85	1
1987	23	0	0	0	0	0	0	0	0	17	30	7	77	2
1988	0	0	0	0	0	10	15	16	18	0	0	0	59	0
1989	0	0	0	0	0	0	0	5	0	2	0	0	7	0
1990	0	0	0	0	0	0	0	0	1	30	0	0	31	1
1991	13	23	0	15	15	30	31	5	21	31	5	6	195	5
1992	0	7	14	0	0	3	24	22	30	31	20	18	169	5
1993	27	28	31	25	0	0	0	0	25	31	30	16	213	7
1994	0	26	10	0	0	19	14	31	30	31	30	31	222	6
1995	31	5	0	0	0	3	26	31	30	31	30	31	218	7
1996	2	0	19	23	7	30	31	3	18	25	26	0	184	5
1997	0	5	7	14	6	29	28	29	30	21	0	17	186	5
1998	15	28	31	10	20	0	0	0	14	31	30	17	196	5
1999	29	13	0	0	0	14	22	7	30	31	30	22	198	6
2000	6	0	0	4	3	0	0	0	0	26	0	0	39	1
2001	0	0	0	0	0	0	21	31	30	31	28	0	141	5
2002	0	15	5	0	0	8	31	4	0	0	0	0	63	1
2003	0	0	0	0	4	30	0	21	18	0	23	0	96	3
Grand Total	289	222	220	212	135	437	494	414	527	750	549	313	4,562	124

Table 7-9. Floodplain Swamp Inundation Analysis for **LD65** and **LD65TB65**: Number of Day in a Month with 20-Day Moving Average Flows Greater Than 110 cfs.

LD65 Flow over 110

	Date													Months with
Years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Grand Total	over 20 days
1965	0	0	0	0	0	0	0	0	0	15	20	0	35	1
1966	11	3	15	0	0	25	31	27	0	22	11	0	145	4
1967	0	0	0	0	0	0	20	21	0	25	19	0	85	3
1968	0	0	0	0	0	26	31	28	18	31	30	1	165	5
1969	0	0	20	0	25	23	11	17	18	31	30	5	180	5
1970	14	23	19	30	11	30	20	0	0	0	0	0	147	4
1971	0	0	0	0	0	0	0	0	19	5	30	4	58	1
1972	10	0	0	0	19	30	11	0	0	0	0	0	70	1
1973	0	0	0	0	0	11	1	30	29	30	5	0	106	3
1974	16	8	0	0	0	15	31	31	2	22	0	0	125	3
1975	0	0	0	0	0	13	24	10	5	19	0	0	71	1
1976	0	0	0	0	8	25	0	0	30	10	0	0	73	2
1977	0	0	0	0	0	0	0	0	27	14	0	17	58	1
1978	6	0	0	0	0	7	31	27	0	20	30	31	152	5
1979	31	13	0	0	0	0	0	0	16	31	22	3	116	3
1980	0	0	0	0	0	0	0	0	0	15	0	0	15	0
1981	0	0	0	0	0	0	0	13	30	14	0	0	57	1
1982	0	0	22	30	27	30	26	0	4	27	29	31	226	8
1983	31	28	31	28	1	21	1	9	30	31	30	31	272	9
1984	23	0	8	14	2	23	0	0	11	24	8	28	141	4
1985	0	0	0	0	0	0	0	0	11	20	0	0	31	1
1986	21	0	3	20	0	9	16	12	0	6	9	1	97	2
1987	23	0	0	0	0	0	0	0	0	18	30	8	79	2
1988	0	0	0	0	0	16	17	19	18	0	0	0	70	0
1989	0	0	0	0	0	0	0	13	0	15	0	0	28	0
1990	0	0	0	0	0	0	0	0	2	31	0	0	33	1
1991	15	23	0	23	16	30	31	5	21	31	5	6	206	6
1992	0	7	14	0	0	4	24	23	30	31	20	18	171	5
1993	27	28	31	25	0	0	0	0	26	31	30	16	214	7
1994	0	26	10	0	0	20	14	31	30	31	30	31	223	7
1995	31	5	0	0	0	3	26	31	30	31	30	31	218	7
1996	2	0	19	23	7	30	31	3	18	25	26	0	184	5
1997	0	5	7	14	6	29	28	29	30	21	0	17	186	5
1998	15	28	31	10	20	0	0	0	14	31	30	17	196	5
1999	29	13	0	0	0	18	22	8	30	31	30	22	203	6
2000	6	0	0	11	4	0	0	0	0	26	0	0	47	1
2001	0	0	0	0	0	0	30	31	30	31	28	0	150	5
2002	0	15	5	0	0	9	31	4	0	0	0	0	64	1
2003	0	0	0	0	6	30	0	22	18	0	23	0	99	3
Grand Total	311	225	235	228	152	477	508	444	547	796	555	318	4,796	133

Table 7-10. Floodplain Swamp Inundation Analysis for **LD90TB110**: Number of Days in a Month with 20-Day Moving Average Flows Greater Than 110 cfs.

LD90 Flow over 110

	Date													Months with
Years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Grand Total	over 20 days
1965	0	0	0	0	0	0	0	0	0	17	21	0	38	1
1966	19	6	16	0	1	30	31	28	16	23	12	0	182	4
1967	0	0	0	0	0	0	23	25	3	28	20	0	99	4
1968	0	0	0	0	0	27	31	31	21	31	30	1	172	6
1969	0	0	22	0	27	27	21	18	22	31	30	5	203	7
1970	15	24	22	30	15	30	23	0	0	0	0	0	159	5
1971	0	0	0	0	13	5	0	0	22	12	30	11	93	2
1972	12	0	0	0	20	30	12	0	0	0	5	0	79	2
1973	0	0	0	0	0	19	4	31	30	31	7	0	122	3
1974	17	9	0	0	0	18	31	31	5	24	0	0	135	3
1975	0	0	0	0	0	20	26	11	11	26	0	0	94	3
1976	0	0	0	0	9	26	0	3	30	20	19	0	107	3
1977	13	3	0	0	0	0	0	0	28	16	0	20	80	2
1978	17	9	0	0	0	24	31	30	10	24	30	31	206	6
1979	31	14	0	0	0	0	0	0	17	31	24	4	121	3
1980	0	0	0	0	0	0	6	13	0	20	0	0	39	1
1981	0	0	0	0	0	0	0	14	30	16	0	0	60	1
1982	0	0	25	30	31	30	27	0	6	28	29	31	237	8
1983	31	28	31	28	4	22	2	15	30	31	30	31	283	9
1984	23	0	8	14	3	24	0	0	11	25	9	29	146	4
1985	0	0	0	13	4	0	0	0	12	23	0	17	69	1
1986	22	1	4	22	0	11	21	13	0	9	17	6	126	3
1987	24	0	18	0	0	0	0	0	0	19	30	10	101	2
1988	0	0	0	0	0	24	18	22	19	0	0	0	83	2
1989	0	0	0	0	0	0	0	19	0	19	0	0	38	0
1990	0	0	0	0	0	0	0	6	14	31	1	0	52	1
1991	16	25	0	26	20	30	31	19	25	31	5	10	238	7
1992	0	8	15	0	0	5	26	25	30	31	22	18	180	5
1993	27	28	31	25	0	14	0	0	30	31	30	17	233	7
1994	0	26	10	3	13	22	17	31	30	31	30	31	244	7
1995	31	5	0	0	0	5	28	31	30	31	30	31	222	7
1996	2	0	20	24	9	30	31	13	19	26	27	0	201	6
1997	0	11	8	16	13	30	30	30	30	21	0	18	207	5
1998	15	28	31	10	22	0	16	1	14	31	30	17	215	5
1999	29	13	0	0	0	21	24	11	30	31	30	22	211	7
2000	6	0	0	15	5	0	0	0	0	29	0	0	55	1
2001	0	0	0	0	0	1	31	31	30	31	28	0	152	5
2002	0	17	5	0	0	10	31	5	0	0	0	0	68	1
2003	0	0	0	0	7	30	1	24	22	0	25	0	109	4
Grand Total	350	255	266	256	216	565	573	531	627	859	601	360	5,459	153

Table 7-11. Floodplain Swamp Inundation Analysis for **LD200** and **LD200TB200**: Number of Days in a Month with 20-Day Moving Average Flows Greater Than 110 cfs.

LD200 Flow over 110

	Date													Months with
Years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Grand Total	over 20 days
1965	31	28	31	30	31	30	31	31	30	31	30	31	365	12
1966	31	28	31	30	31	30	31	31	30	31	30	31	365	12
1967	31	28	31	30	31	30	31	31	30	31	30	31	365	12
1968	31	29	31	30	31	30	31	31	30	31	30	31	366	12
1969	31	28	31	30	31	30	31	31	30	31	30	31	365	12
1970	31	28	31	30	31	30	31	31	30	31	30	31	365	12
1971	31	28	31	30	31	30	31	31	30	31	30	31	365	12
1972	31	29	31	30	31	30	31	31	30	31	30	31	366	12
1973	31	28	31	30	31	30	31	31	30	31	30	31	365	12
1974	31	28	31	30	31	30	31	31	30	31	30	31	365	12
1975	31	28	31	30	31	30	31	31	30	31	30	31	365	12
1976	31	29	31	30	31	30	31	31	30	31	30	31	366	12
1977	31	28	31	30	31	30	31	31	30	31	30	31	365	12
1978	31	28	31	30	31	30	31	31	30	31	30	31	365	12
1979	31	28	31	30	31	30	31	31	30	31	30	31	365	12
1980	31	29	31	30	31	30	31	31	30	31	30	31	366	12
1981	31	28	31	30	31	30	31	31	30	31	30	31	365	12
1982	31	28	31	30	31	30	31	31	30	31	30	31	365	12
1983	31	28	31	30	31	30	31	31	30	31	30	31	365	12
1984	31	29	31	30	31	30	31	31	30	31	30	31	366	12
1985	31	28	31	30	31	30	31	31	30	31	30	31	365	12
1986	31	28	31	30	31	30	31	31	30	31	30	31	365	12
1987	31	28	31	30	31	30	31	31	30	31	30	31	365	12
1988	31	29	31	30	31	30	31	31	30	31	30	31	366	12
1989	31	28	31	30	31	30	31	31	30	31	30	31	365	12
1990	31	28	31	30	31	30	31	31	30	31	30	31	365	12
1991	31	28	31	30	31	30	31	31	30	31	30	31	365	12
1992	31	29	31	30	31	30	31	31	30	31	30	31	366	12
1993	31	28	31	30	31	30	31	31	30	31	30	31	365	12
1994	31	28	31	30	31	30	31	31	30	31	30	31	365	12
1995	31	28	31	30	31	30	31	31	30	31	30	31	365	12
1996	31	29	31	30	31	30	31	31	30	31	30	31	366	12
1997	31	28	31	30	31	30	31	31	30	31	30	31	365	12
1998	31	28	31	30	31	30	31	31	30	31	30	31	365	12
1999	31	28	31	30	31	30	31	31	30	31	30	31	365	12
2000	31	29	31	30	31	30	31	31	30	31	30	31	366	12
2001	31	28	31	30	31	30	31	31	30	31	30	31	365	12
2002	31	28	31	30	31	30	31	31	30	31	30	31	365	12
2003	31	28	31	30	31	30	31	31	30	31	30	31	365	12
Grand Total	1,209	1,101	1,209	1,170	1,209	1,170	1,209	1,209	1,170	1,209	1,170	1,209	14,244	468

In the **BASE** condition scenario (**Table 7-8**), there are 18 years during the 39-year period of record that had four or more months with a 20-day moving average daily flow greater than 110 cfs. The **LD65** and **LD65TB65** scenarios improved this by just one more year as shown in **Table 7-9**. Scenario **LD90TB110** resulted in 5 additional years (**Table 7-10**). The **LD200** and **LD200TB200** scenarios provided floodplain inundation year around, which is not a healthy condition for the floodplain vegetation.

To examine the performance of wet season flows for each scenario on hydric hammock communities, the number of days of inundation was counted if the flow was greater than 180 cfs, 240 cfs, and 340 cfs, which correspond to the low, median and high elevation occurrences of the hydric hammock areas at Transect #1 for the **BASE** condition. The results for the **BASE** condition**, LD65, LD65TB65,** and **LD90TB110** scenarios were the same because the added flow did not reach 180 cfs. Each scenario experienced 29 years of the 39-year POR when daily flow was over 180 cfs for more than 30 days in a year, 18 years when daily flow was over 240 cfs for more than 30 days in a year, and 3 years when daily flow was over 340 cfs for more than 30 days in a year. Both **LD200** and **LD200TB200** scenarios produced flows that resulted in prolonged periods of inundation and therefore would be detrimental to the hydric hammock communities.

These results also suggest that the frequency distribution of flows larger than 180 cfs under these conditions should be sufficient to meet the inundation requirements of the hydric hammock communities.

EVALUATION OF TIDAL FLOODPLAIN

Evaluation Methods

In **Chapter 4**, a salinity regimen defined by the *Ds*/*Db* ratio as a performance measure to evaluate the Northwest Fork restoration scenarios was described. A quantitative tool was developed by SFWMD staff. It is based on the correlation of a measured vegetation abundance index and the *Ds*/*Db* ratio along the Northwest Fork (Zahina 2004). Definitions for the abundance index values are provided in **Table 7-12**. The vegetation abundance index at RM 10.6 is used as a “reference” freshwater floodplain community to characterize a “healthy” community of the floodplain swamp (**Figure 7-6**). Two vertical dashed lines are shown on each graphic dividing the species into three general groups. The left-most group contains red mangrove, which is a species characteristic of saltwater communities. The middle species group contains pond apple, cabbage palm, and bald cypress, which are freshwater swamp tree species that exhibit some tolerance for saltwater (Zahina 2004). The right-hand group contains red maple, Virginia willow, dahoon holly and pop ash, which are species that are sensitive to saltwater exposure and are expected to be the first to show stress from saltwater intrusion. The right-hand group is stressed when the abundance index for all species is below 2 and when a *Ds*/*Db* ratio nears 0.3. A *Ds*/*Db* ratio of 1 almost eliminates all four salinity sensitive species. This tool, called Salinity-Vegetation Model for the Loxahatchee River (SAVELOX; Zahina 2004) is used for rapid analyses of long-term salinity time-series data for sites along the near shore areas of the Northwest Fork of the Loxahatchee River.

Table 7-12. Abundance Index Definitions.

Description of Species Population Density	Abundance Index
1a. Species not present	0
1b. Species present.	
2a. Two or less individuals; rare	1
2b. More than two individuals.	
3a. Highly abundant or dense population (>75% cover), a dominant component of the plant community	4
3b. Species not a dominant component of the plant community.	
4a. Sparse; widespread and of low density or restricted to localized populations	2
4b. Common; widespread and of moderate density but not a dominant component of the plant community (<50% cover)	3

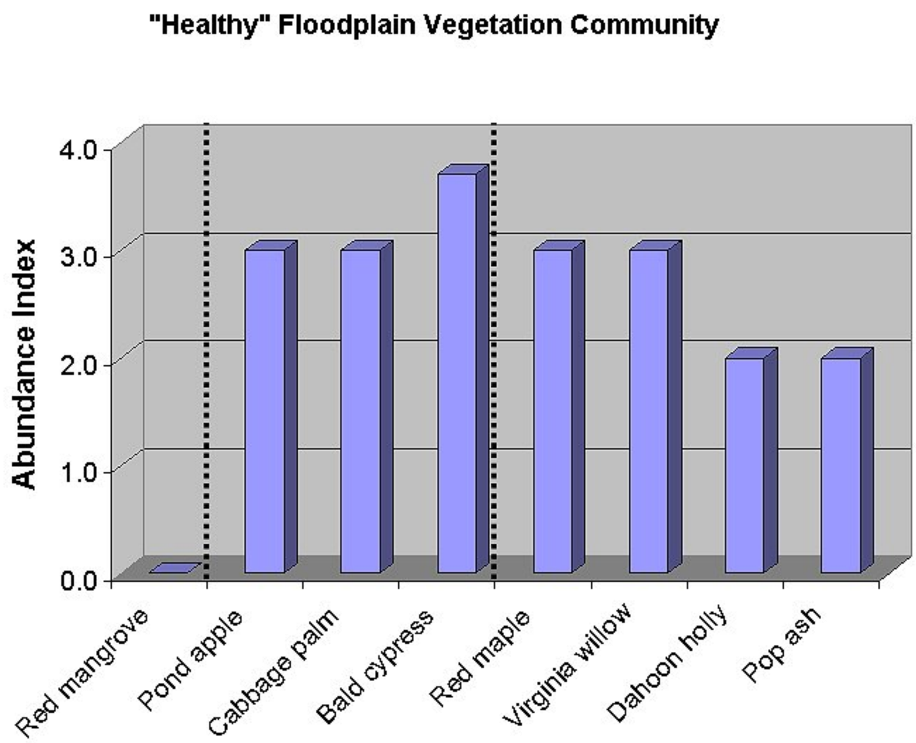


Figure 7-6. Reference "Healthy" Floodplain Swamp Community from the SAVELOX Model.

Four upstream sites that lie within Jonathan Dickinson State Park and along the "Wild and Scenic" River Corridor were included in this analysis: RM 9.12, KC at RM 8.13, VT9 at RM 7.06 and Boy Scout Dock at RM 5.92. For each of the restoration scenarios, the *Ds*/*Db* ratios at these four sites were calculated and the resulting salinity regimes in relationship to the vegetation abundance index were simulated with SAVELOX.

Results and Discussion

Table 7-13 presents the *Ds*/*Db* ratios for the base condition and the five constant flow scenarios. Salinity-exposure events increased in magnitude and frequently from RM 9.12 to Boy Scout Dock (RM 5.92) for all flow conditions. A *Ds*/*Db* value over 0.3 indicates salinity stress for the salinity sensitive species. It should be noted that as with any model, caution needs to be taken when interpreting SAVELOX modeling results. In this case, other important environmental factors that play significant roles in shaping the composition of plant communities (such as elevation and logging) are not considered. These environmental factors were considered separately and those results, with a consideration of site salinity, will provide a better indication of appropriate conditions for restoration.

Table 7-13. An Analysis of a **1 ppt Salinity Threshold** at 4 Sites Along the Northwest Fork of the Loxahatchee River: Ratio of Salinity Event Duration (*Ds*, days) and Time Between Events (*Db*, days).

Station	Constant Flow Restoration Scenarios					
	BASE	LD65	LD65TB65	LD90TB110	LD200	LD200TB200
Boy Scout Dock RM 5.92	57.64	54.49	54.49	46.79	32.32	17.73
VT9 RM 7.06	5.92	5.40	5.11	3.76	0.85	0.00
KC RM 8.13	1.71	1.47	1.00	0.00	0.00	0.00
RM 9.12	0.62	0.02	0.00	0.00	0.00	0.00

The resulting vegetation community simulated with the SAVELOX site at RM 9.12 is shown in **Figure 7-7**. Examination of the **BASE** indicates that a mix of saltwater-tolerant and freshwater species is present at this site. The predicted vegetation composition shows a habitat that is fresher than what is observed under current conditions. This appears to be justified because the **BASE** assumes that G-92 operates under the current operation scheme throughout the entire 39-year POR. However, adverse impacts occurred in the floodplain prior to the construction of G-92. In conclusion, a flow of 65 cfs or higher provides sufficient freshwater to support a freshwater floodplain community at this site. The abundance index of bald cypress and other freshwater species are all above 2.

The SAVELOX Model analyses of site KC (RM 8.13) salinity time series are shown in **Figure 7-8**. The **BASE** floodplain community at this site is dominated by red mangrove with remnants of freshwater vegetation (pond apple, cabbage palm and bald cypress). The model results, however, predict little change at this site between the **LD65** and **LD65TB65** scenarios. Upon examination of the salinity time series, it was noted that the magnitude and duration of salinity events above 1 ppt had been significantly reduced in the **LD65TB65** scenario as compared to the LD65 scenario (**Figure 7-9**). When calculating the *Ds/Db* ratio with the long-term salinity time series data, all values were rounded to whole numbers to be conservative. A close examination of the long-term salinity data for the LD65TB65 scenario indicates that the salinity during the dry season is usually between 0.5 ppt to 0.7 ppt (**Figure 7-9**). The method of rounding the salinity data up yielded a *Ds/Db* ratio close to 1.0 at site KC (RM 8.13), which would otherwise be close to 0. To better understand tidal influence on salinity fluctuation on this site, a model run using the hydrodynamic and salinity model (RMA) was conducted to examine salinity during a lunar month (28 days) with a constant flow of 130 cfs distributed accordingly in all tributaries of the Northwest Fork. The result is presented in **Figure 7-10** which indicates that the salinity was above 1 ppt only briefly at high tides during the spring tide (7 out of 28 days). The daily average salinity is still well below 1 ppt. This confirms that a *Ds/Db* ratio of 1.0 is not a true reflection of salinity regimen at this site, but an artifact of rounding up the salinity data. Thus, recovery of the freshwater vegetation at the Kitching Creek site is likely to occur with the **LD65TB65** scenario. In this case, the SAVELOX Model produced an output that is more conservative on the side of restoration than was expected to occur.

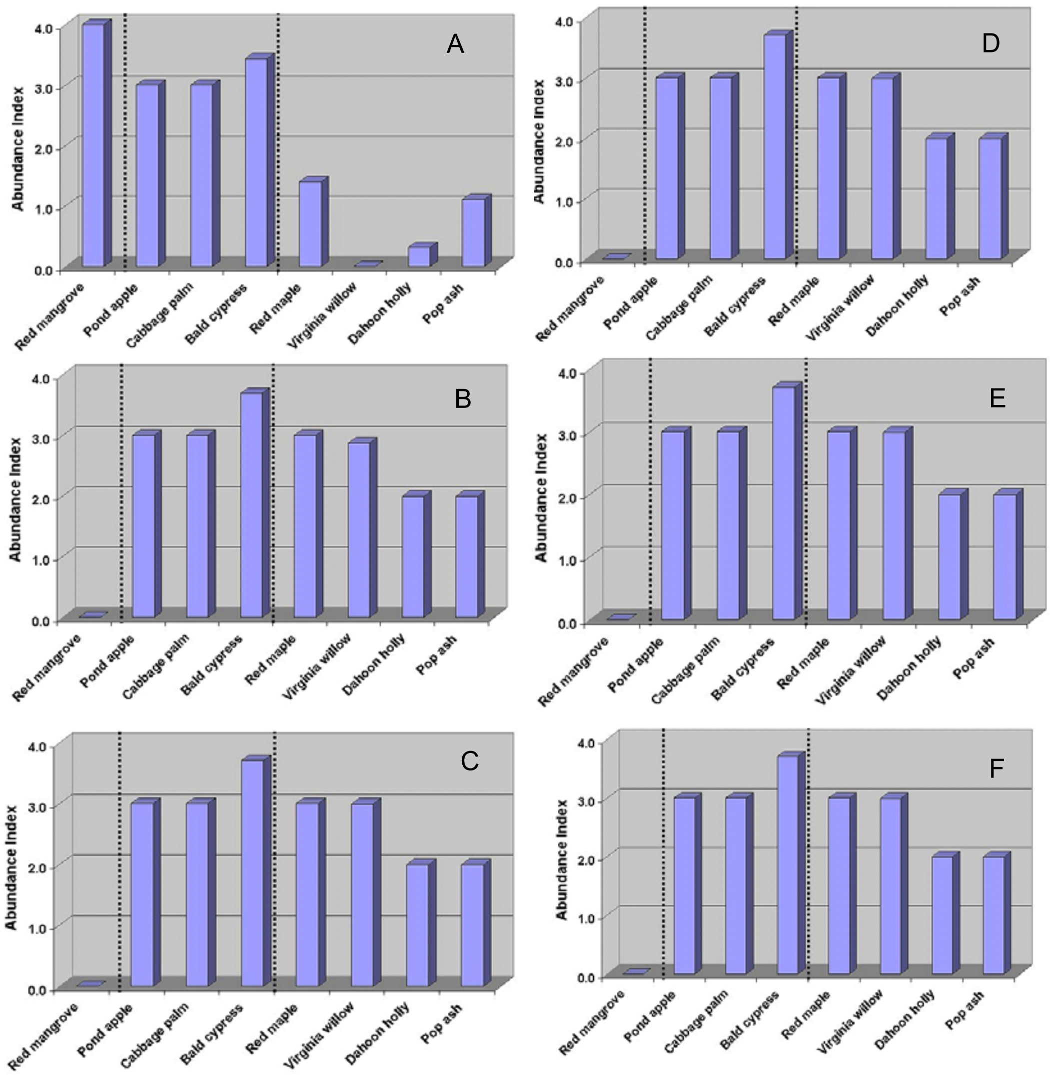


Figure 7-7. SAVELOX Model Analysis of Site RM 9.12: A. BASE, B. LD65, C. LD65TB65, D. LD90TB110, E. LD200, and F. LD200TB200.

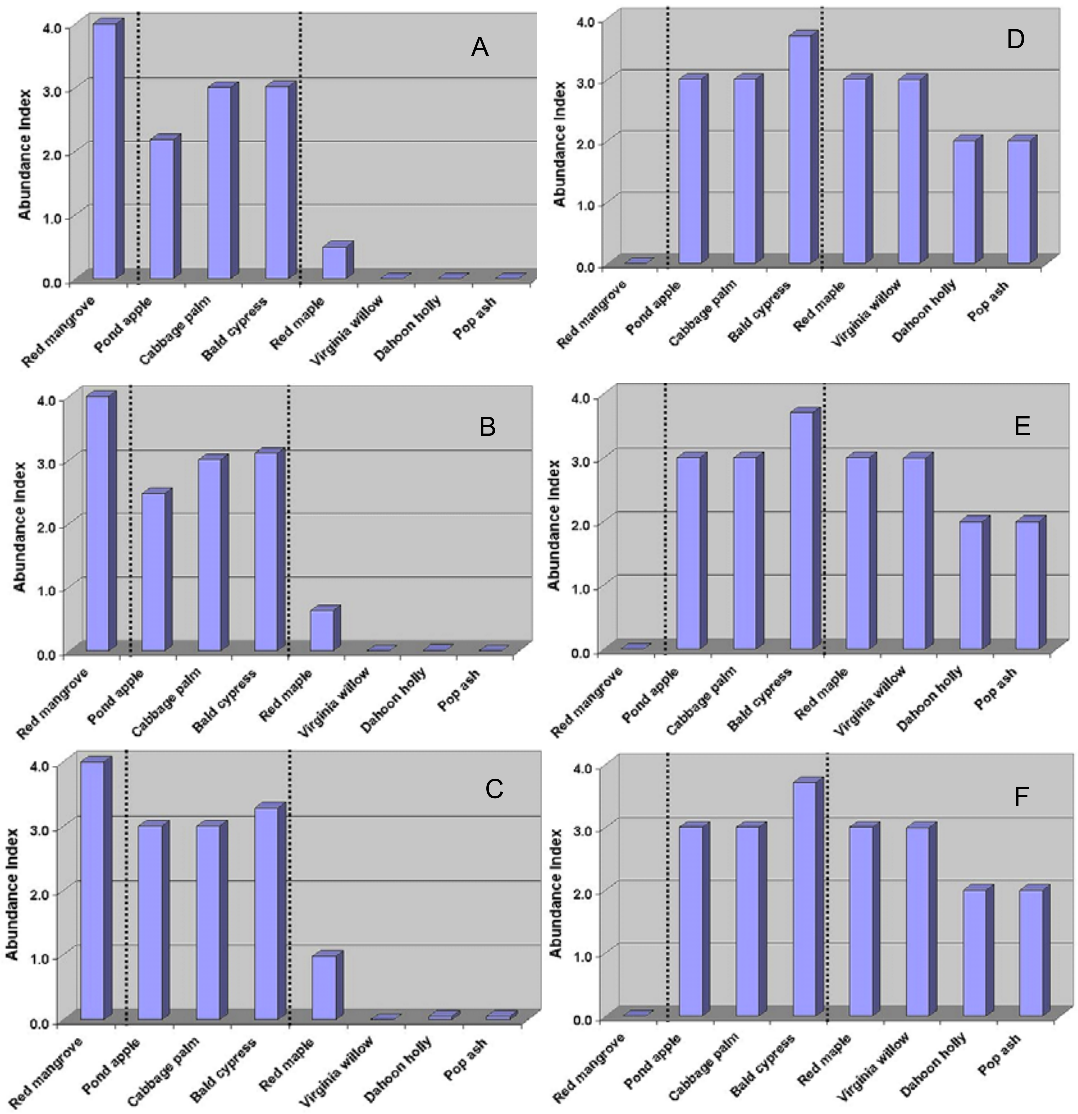
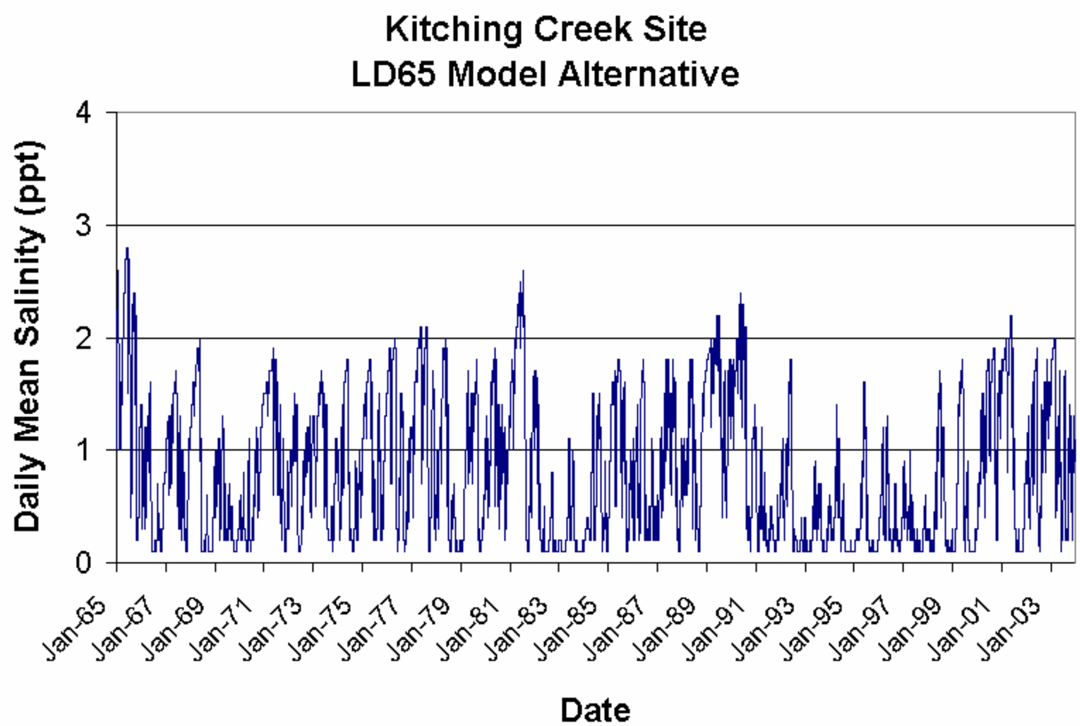


Figure 7-8. SAVELOX Model analysis of Kitching Creek Site (RM 8.13): A. BASE, B. LD65, C. LD65TB65, D. LD90TB110, E. LD200, and F. LD200TB200.



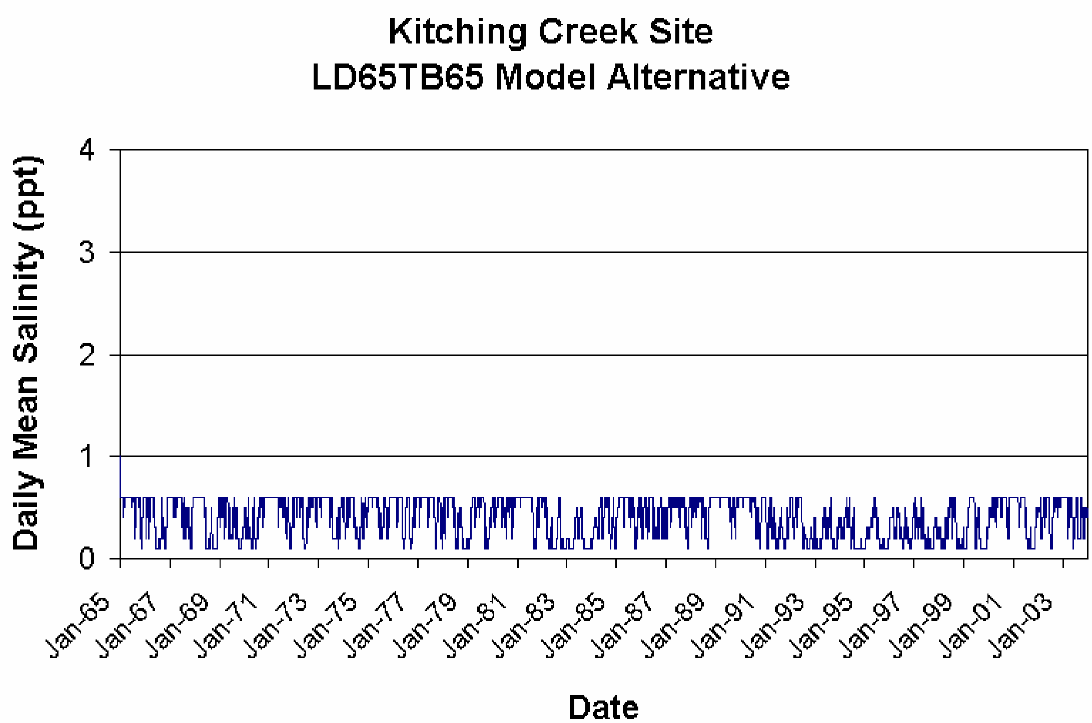


Figure 7-9. Modeled Salinity Time Series at the Kitching Creek Site for Constant Flow Scenarios **LD65** and **LD65TB65.**

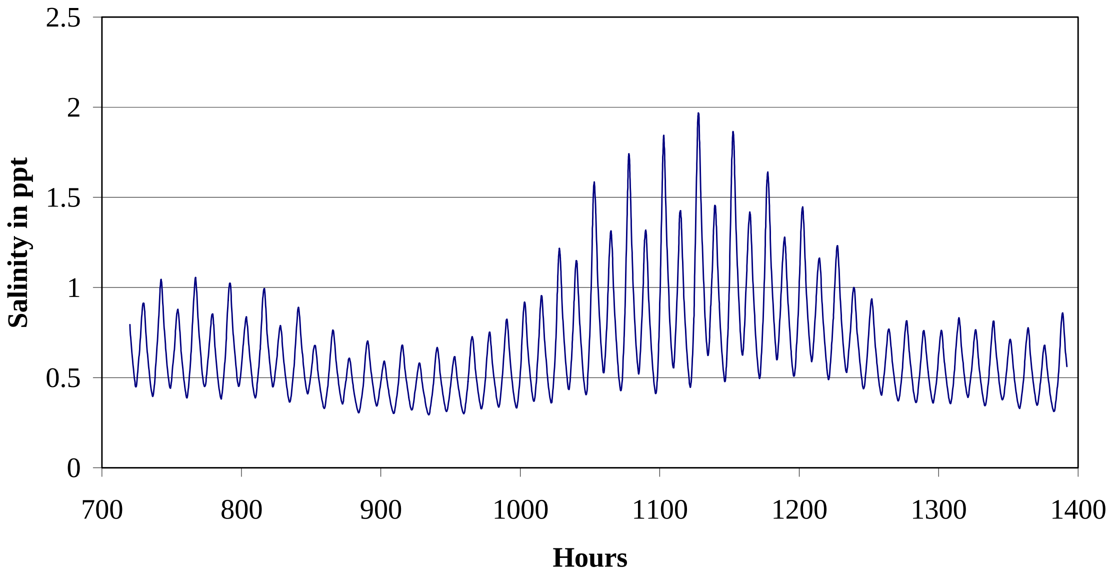


Figure 7-10. RMA Model Output of Salinity at Kitching Creek Station (KC at RM 8.13) Over a Lunar Month with Total Freshwater Flow to the Northwest Fork of 130 cfs (**LD65TB65**).

In the tidal reaches, it is anticipated that additional freshwater flows will flush salt from surface, groundwater and soils. Also, with increased freshwater flows more nutrients may be delivered across the floodplains during the growing season. Additional nutrients may improve the production of target species seeds or sapling production. Furthermore, the additional freshwater flows may discourage the further spread of upland and transitional species, assist in the control of some exotics, and encourage the growth of freshwater deciduous tree and understory species within the floodplains. The evaluation shows that a combined flow in the range of 130 cfs to 200 cfs from Lainhart Dam and the other tributaries is required to provide sufficient freshwater to support freshwater riverine floodplain vegetation down to the mouth of Kitching Creek. It is recognized that the occasional very dry season will provide good conditions for freshwater tree seedling and sapling production and germination to rebuild the forest communities as they age.

A combined flow of greater than 400 cfs would be required to provide freshwater conditions to the edge of Jonathan Dickinson State Park. However, sustaining a flow of 400 cfs would result in a significant change to the present river flow patterns. Large increases in flows have the potential to: 1) increase the elevation of surface water across the floodplain; 2) produce large increases in hydroperiods within the floodplain; 3) increase the potential for scouring and deepening of the river channel; 4) increase the potential for bank erosion and shifts in the course of the river channel; 5) transport of sediment and silt to the downstream estuary and 6) substantially reduce or eliminate low water (dry down) events in the floodplain swamp. All of these factors can have significant adverse impacts to existing floodplain vegetation. These additional issues (besides salinity) need to be considered when examining the desirability of a restoration flow scenario for enhancing freshwater floodplain vegetation. An example of these concerns is that high flows during the dry season would impede germination of bald cypress and hinder seedling/sapling growth due to over inundation. Operational modifications will be required for the selected scenario to create an occasional dry season exclusively for bald cypress germination, and seedling/sapling production, to increase new recruits into the floodplain swamp community.

In the restored floodplain communities, once salinity levels are reduced or eliminated, freshwater plant species are expected to return to the desired distribution over time. Again, elevation appears to be the major factor in the distribution of forest types. In the upper tidal reach, the restored freshwater floodplain swamp communities would be represented predominantly by bald cypress and pond apple communities. The few mangroves in the upper tidal section should revert to sub-canopy level within the vegetative swamp communities with the growth of freshwater canopy trees over time. Hydric hammocks would be dominated by cabbage palm in both reaches. However, due to the dominance of swamp communities and the narrow transitional area between uplands and swamp communities in the tidal floodplain, true hydric hammock communities would be rare. A mixed forest type of swamp and hydric hammock species may prevail. Other freshwater plant species (pop ash, red maple, Carolina willow, etc.) are expected to be present in lower numbers. Additionally, increases in light availability (due to historic logging activities, hurricane impacts, or exotic removal or treatment) in the riverine and upper tidal reaches may improve recruitment of other freshwater target species and keep species diversity high.

In the lower tidal reach where mangrove swamps are the dominant feature, the recruitment of freshwater seedlings and saplings would be hindered by the thickness of the mangrove root systems, persistent tidal inundation due to low elevations, and low levels of light reaching the forest floor. Thus, in spite of the anticipated changes in the tidal floodplain vegetation community, the canopy and shrub-size mangroves are expected to remain in areas where mangroves are the predominant species, such as at VT9 (RM 7.06) and the JDSP boundary (RM 6). The presence of mangroves in this limited segment can be viewed as beneficial since it is a buffer between the saline and fresh water environment and it provides essential habitat for tidal wetland and estuarine ecosystems for benthic organisms, juvenile fish, and wading birds.

EVALUATION OF LOW SALINITY ZONE: FISH LARVAE

Evaluation Methods

During the dry season when freshwater flows are minimal, there is a major influx of tropical fish larvae (Gilbert and Kelso 1971; Nordlie 1979, 1981; Gilmore 1993). Many of these fish larvae species utilize the Low Salinity Zone (LSZ) of the Loxahatchee estuary from 2 ppt to 8 ppt as critical larval nursery habitat. When larvae develop into juveniles they seek the shallow waters and vegetated shorelines for protection from predation and an abundant food supply. This essential juvenile habitat is readily available between about RM 10 and RM 6 where numerous shallow tidal creeks and vegetated shorelines exist. A preferred dry season flow would allow an overlapping of essential larvae and juvenile habitats. This can be accomplished by avoiding salinities lower than 8 ppt during the dry season at the most downstream location of essential juvenile habitat near RM 5.5.

In order to characterize the relationship between salinity and flows to the Northwest Fork, hydrodynamic/salinity modeling determined a family of curves that shows the expected average daily salinity at any River Mile while constant flows are introduce to the system (**Figure 7-11**). These curves best represent salinity conditions when low variable flows occur mostly during the dry season. Since supplemental flows under consideration were going to be introduced at a constant rate during the dry season, the family of curves which represents steady state equilibriums can be used to assess the affects of various flows on salinity near RM 5.5.

Results and Discussion

Two studies were conducted to determine the species composition and distribution of fish larvae and other zooplankton in the Loxahatchee estuary. Details of these studies are in **Chapter 4** and **Appendix H**. The first study occurred during 1986-1988 and the second in the 2004 dry season. These studies revealed the highest densities of fish larvae were found within the

LSZ where salinity levels ranged from 2 ppt to 8 ppt. Specifically, the greatest concentration of fish larvae within this salinity range occurred near RM 7 during 1986-1988 and between RM 8 and RM 9 in 2004 (**Figure 7-11)**, with most larvae being captured in the vicinity of the mouth of Kitching Creek at RM 8. The highest density of fish larvae captured in the Pautuxent River (Shenker et al. 1984) were captured between salinities of 2 ppt to 3 ppt. Similar salinity association patterns were observed in the San Francisco Estuary (Dege and Brown 2004). Apparently, fish larvae concentrate in the Low Salinity Zone of estuarine systems; however, since each system has unique characteristics, these field investigations needed to document the unique low salinity range for the Loxahatchee estuary.

The preferred salinity range for larval fish in the Loxahatchee should not advance downstream of about RM 5.5 for several reasons. The quality and area of nursery habitat may be significantly reduced downstream from RM 5.5 due to physical changes in the waterway (see **Chapter 3**, **Table 3-5**) and the impact of human influences such as artificial lighting, hardening of shorelines (seawalls) and loss of shallow shoreline transitional habitat. Additionally, the natural concentration of fish larvae, due to many physiochemical parameters, will not likely occur further downstream than about RM 5.5 due to the change in physical characteristics in this area. Therefore, analysis is necessary to determine the maximum amount of base flow that can be delivered to the system while minimizing the number of occurrences of salinities below 8 ppt near RM 5.5.

Figure 7-11 shows a family of curves relating salinity and flows from about RM 1 to RM 9 with the preferred fish larval salinity range of 2 ppt to 8 ppt delineated. These curves are the results of multiple simulations by the RMA model (see **Chapter 6**). Upon inspection of the figure, the predicted salinity at RM 5.5 will generally be 8 ppt when combined flows are about half way between 159 cfs and 238 cfs or near 170 cfs. According to the criteria established, scenario **LD65TB65,** with a combined flow of 130 cfs, would conservatively be the scenario protecting the fish larvae habitat. Scenarios with combined flows greater than 170 cfs (**LD90TB110, LD200, LD200TB200**) would increase the frequency of undesirable low salinities upstream RM 6 and therefore cause a reduction of essential habitat for fish larvae.

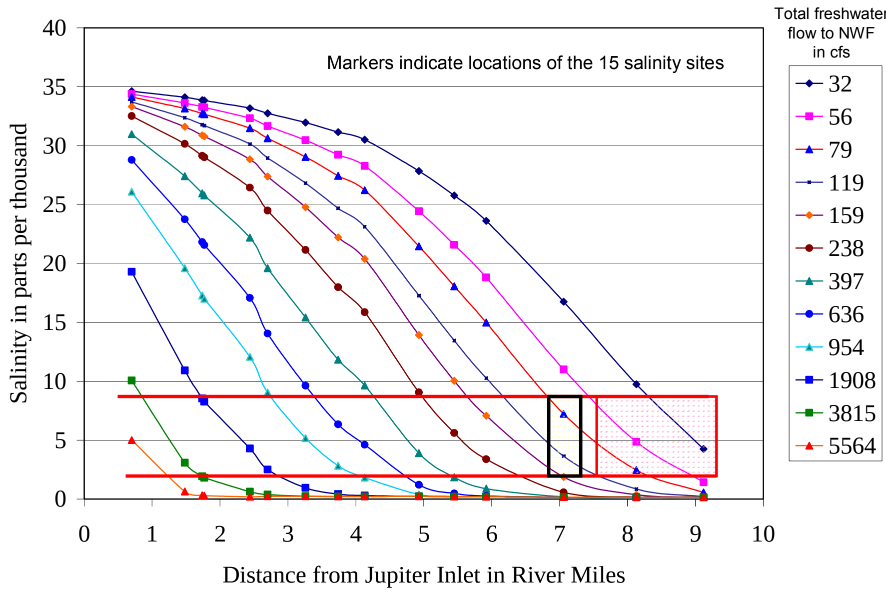


Figure 7-11. Location (in River Miles) of Low Salinity Zone (LSZ) with Varying Freshwater Flows. Red Bars Represent 2 ppt to 8 ppt Salinity Range. Red Shaded Rectangle Represents Largest Ichthyoplankton Captures During June-July 2004. Yellow Shaded Rectangle Represents Largest Ichthyoplankton Captures During 1986-1988.

EVALUATION OF MESOHALINE ZONE: OYSTERS

Evaluation Methods

Favorable estuarine habitat conditions for the eastern oyster are predominately determined by salinity, quality and quantity of food, available substrate (cultch), water flow, presence of disease organisms, and predation. Low densities (167 oysters/m^2 at RM 5.9) manifest poor oyster habitat conditions in the upstream portion of the Northwest Fork primarily due to frequent exposures to unfavorable low salinities while low densities in the outer estuary (downstream of RM 4.2) may result from disease (*Perkinsus marinus*), predation, limited food supply, and lack of appropriate substrate. Suitable oyster habitat exists in the middle portion of the Northwest Fork from where yearly salinity averages are approximately between 10 ppt to 20 ppt. As yearly average salinity increases in from RM 6 to RM 4, the density of oysters also increases to a maximum of 901 oysters/m^2 at RM 4.5 (see **Chapter 4, Figure 4-14**). The increase in oyster density is indicative of more favorable habitat conditions, with the existing hydrology, for reproduction, growth, and reduced influence of disease and predators. The restoration flow scenario evaluation for oysters is limited to this area where disease and predation are minimized. Oyster life history and salinity thresholds to address stress are used as the controlling factors of oyster presence, even though other factors are undoubtedly important, they are difficult to quantify and beyond the scope of this evaluation.

To describe the relative suitability of habitat within the area of interest, salinity tolerance thresholds for each life stage were established. Although overlapping life stages were observed throughout the year, major spring spawning usually occurs in March and April when water temperatures are rising. Any protracted spawning during the year is considered insignificant even though other Florida estuaries appear to experience a minor fall spawn (Volety et al. 2003). Therefore, salinity concentrations and duration thresholds for oyster life stages (eggs, larvae, spat, and adult) that cause stress, harm, and mortality were introduced as the oyster Performance Measures where larval presence from March to May follows egg development from January to April (**Chapter 4, Table 4-3**). Spat and juvenile oysters are present from April through July while year class adults are present from June to December.

This salinity tolerance and life stage information were used to develop a Loxahatchee Oyster Stress Model (LOSM) that determines the number of days of "no salinity stress" (good conditions), stress (mixed conditions), and mortality (unhealthy conditions) for each life stage during the year throughout the oyster bars distributed in the middle of Northwest Fork (RM 4.1 to RM 5.9). The percent of time within one year for each level of stress is obtained from the LOSM model. To reduce the variability of salinity, a daily mean salinity value is used as input to the model. Long-term daily salinities (from 1965 to 2003) at four locations near oyster beds documented in a November 2003 survey (Bachman et al. 2004) were simulated using the LSMM. In addition to the **BASE** case and the five flow restoration scenarios, two additional scenarios were evaluated. These two scenarios are, **LD60TB40** representing a flow of 60 cfs from Lainhart Dam and 40 cfs from the other tributaries, creating a combined flow of 100 cfs into the Northwest Fork, and **LD80TB80** representing a flow of 80 cfs from Lainhart Dam and 80 cfs from the other tributaries, creating a total of 160 cfs into the Northwest Fork. All scenarios were compared and contrasted with the **BASE** to determine the maximum flow to the Northwest Fork without significantly harming oyster resources. To visualize how levels of oysters stress varied among years, an EXCEL stackable bar chart was utilized. Box and whisker plots (Sokal 1965) were generated, with the statistical software SYSTAT 10.2. This was done to visually depict the distribution of 39 years of oyster salinity stress levels for all salinity time series by revealing the median percent of days per year of stress and harm as well as death conditions, 95% confidence limits, and range of data.

Major assumptions of this assessment are 1) most of the variability associated with the success of a year class of oysters can be explained by exposure to daily mean salinities (or salinity as a surrogate) during four life stages; 2) the life history of oysters in the Northwest Fork estuarine area emulates that in St. Lucie estuary oysters; and 3) a long-term evaluation of oyster habitat suitability can be determined by assessing salinity conditions for each year class.

Results and Discussion

The LOSM model used 39 years of modeled, daily estuarine flows to predict average daily salinities at four locations in the Northwest Fork (**Chapter 6, Figure 6-15**). Levels of stress for up to eight flow scenarios were determined. These four stations are BD (Boy Scout Dock at RM 5.92), Oyster Station 6 (RM 5.45), Oyster Station 5 (RM 4.93), and Oyster Station 4 (RM 4.13) as shown in **Figure 7-12**.

Figure 7-12. Oyster Evaluation Stations in the Northwest Fork of the Loxahatchee River. The Oyster Beds Surveyed in 2003 Are Shown in Yellow. Red Dots Are Monitoring Sites.

For each constant flow scenario, the level of stress on the oyster year class (four life stages) was determined by comparing these salinities with salinity stress thresholds. **Figures 7-13, 7-14,** and **7-15** provide an example of how the output from the model was used to visualize affects of all scenarios flows on the year class life stages. These figures show the percent of time each year class experienced one of three levels of stress for the **BASE** case and two scenarios. The **BASE** case (**Figure 7-13**) reveals that good conditions existed for egg development at RM 4.93 (Station 5) during most years. As flows increased with successive scenarios and were compared to the **BASE** case, more oyster stress was observed. For example, **Figure 7-14** shows scenario **LD90TB110**, (combined flow of 200 cfs) increased the percent of time oyster egg development was exposed to mixed (harmful) and bad (mortality) salinity conditions. However, a dramatic increase in harm and mortality was evident for scenario **LD200** with a total flow of about 230 cfs (**Figure 7-15).** Therefore, the maximum base flow before major adverse salinity conditions occur for oyster eggs at RM 4.93 is about 200 cfs. A total of 128 plots were visually inspected to select the preferred flow scenario for all life stages as demonstrated with these figures for egg development. All of these results were compiled for comparison and validation with the results from the following analysis.

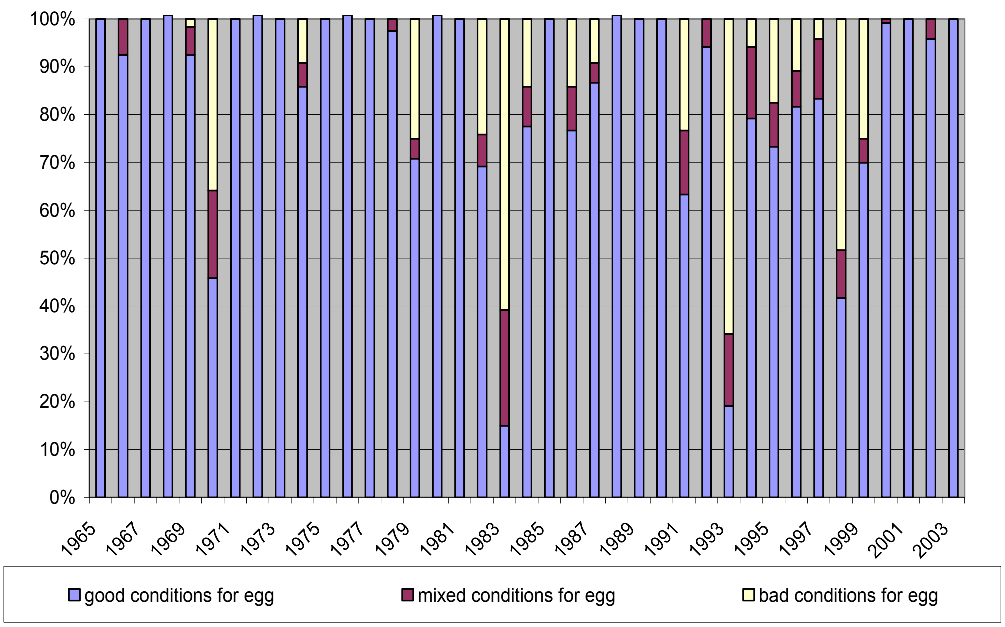


Figure 7-13. Percent of Time for Three Levels of Salinity Stress on Oyster Eggs at Station 5 (RM 4.93) for the **BASE** Case.

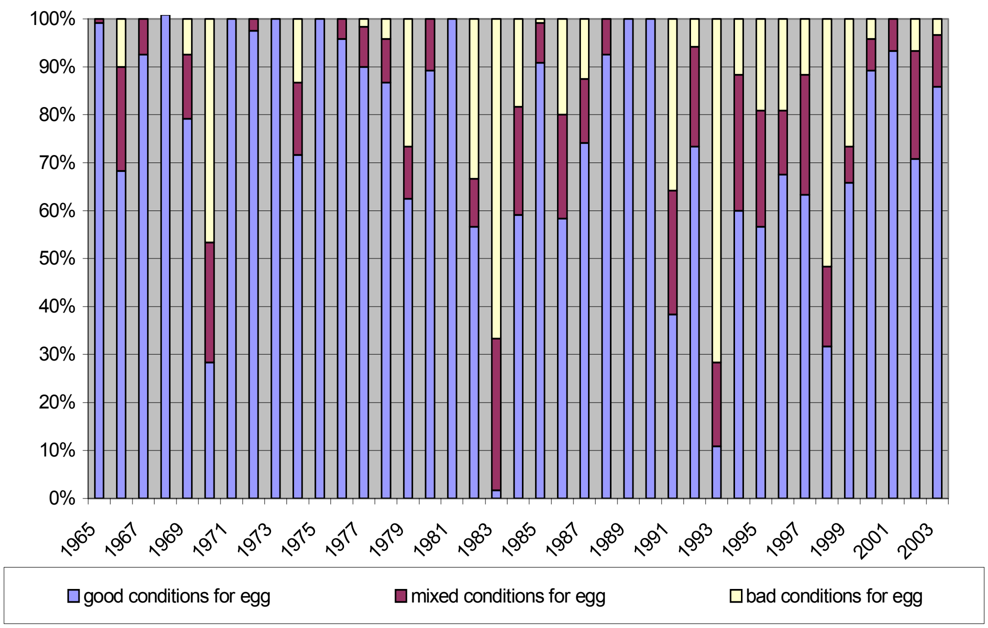


Figure 7-14. Percent of Time for Three Levels of Salinity Stress on Oyster Eggs at Station 5 (RM 4.93) for the **LD90TB110** Scenario.

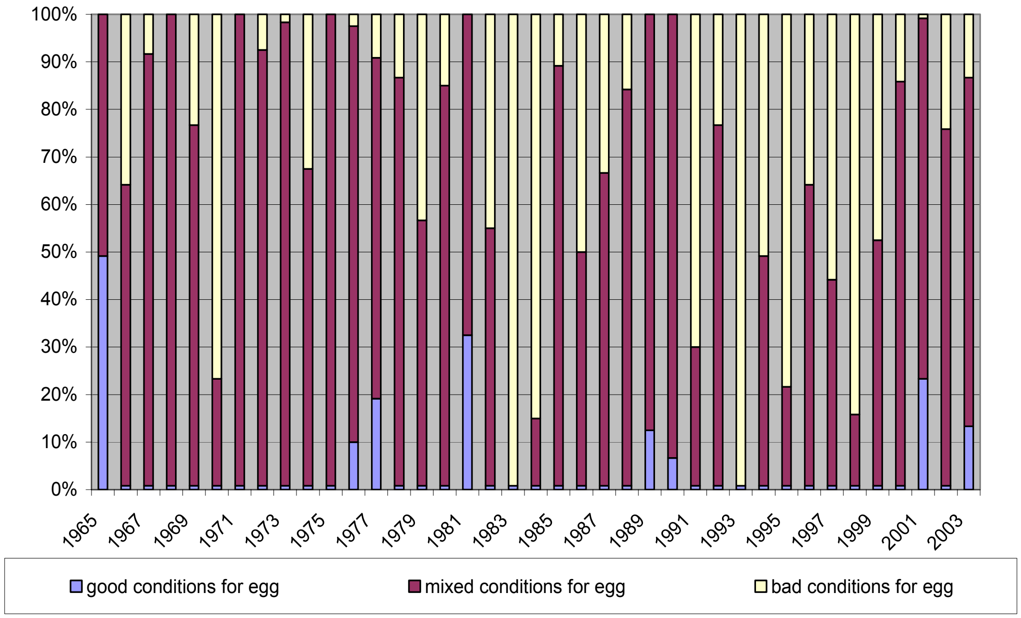


Figure 7-15. Percent of Time for Three Levels of Salinity Stress on Oyster Eggs at Station 5 (RM 4.93) for the **LD200** Scenario.

In addition to the visual analysis graphs, individual year class evaluation for each life stage, the median, 95% confidence limits and range of the 39-year distribution of percent of time for death and harm/stress conditions were depicted with box and whisker plots (BWP) for all life stages at four stations in **Figures 7-16** through **7-23**. As an example of the linkage between the visual analysis (**Figures 7-13, 7-14** and **7-15**) and the BWP (**Figures 7-20** and **7-21**) for Station 5, depicts information in which the visual analysis concluded significant harm condition for eggs occurring with flows greater than scenario **LD90TB110**. It is apparent that the 39-year distribution data for scenarios validate the visual analysis.

As a performance measure, the existing oyster resources, and the flow scenarios for each station are those that avoid stress to the most salinity sensitive life stage; oyster larvae. These larvae are present in the system during the late dry season (March, April, and May; see **Chapter 4**, **Table 4-3**) which is the time period the evaluation was conducted for this life stage and when problems with saltwater intrusion historically occur. Oyster larvae at the most upstream station (Boy Scout Dock at RM 5.92) are the most sensitive to increased flows. Flows greater than scenario **LD65** (combined flow of 95 cfs) will result in a significant increase in stress (**Figure 7-16**) and a significant increase in unhealthy conditions in this area may occur with flow scenario **LD60TB40** (100 cfs, **Figure 7-17**).

Additional results for downstream Oyster Station 6 at RM 5.45, are shown in **Figures 7-18** and **7-19** and indicate that the flows in scenario **LD65TB65** (130 cfs) causes stress to the larvae. Using the same logic for larvae at Oyster Station 5 at RM 4.93, **Figures 7-18** and **7-19** reveal that flow scenario **LD80TB80** (160 cfs) is the flow which causes stress and flow scenario **LD90TB110** (200 cfs) for death. A dramatic increase in stress occurs from flow scenarios **LD80TB80** to **LD90TB110** (**Figure 7-20**). However, it dramatically decreases from flow scenarios **LD90TB110** to **LD200** due to the increase in death occurring with scenario **LD200**. This decrease in stress/harm with increasing flows can be observed at other stations. The least impact on oyster larvae by increases in flows is the most downstream Station 4 (RM 4.13). **Figures 7-22** and **7-23** show that Station 4 can tolerate scenario **LD 200** (230 cfs) before significant stress/harm occurs with **LD200TB200** (400 cfs). Therefore, any restoration flow scenario that increases the flow greater than 90 cfs to 100 cfs will adversely impact the existing upstream oyster bars. However, if flows greater than 90 cfs to 100 cfs are needed to restore other important upstream habitats, the loss of the most upstream highly stressed oysters at RM 5.92 can be mitigated by providing additional substrate (cultch) in downstream areas near RM 4.5 that would be experiencing favorable salinities.

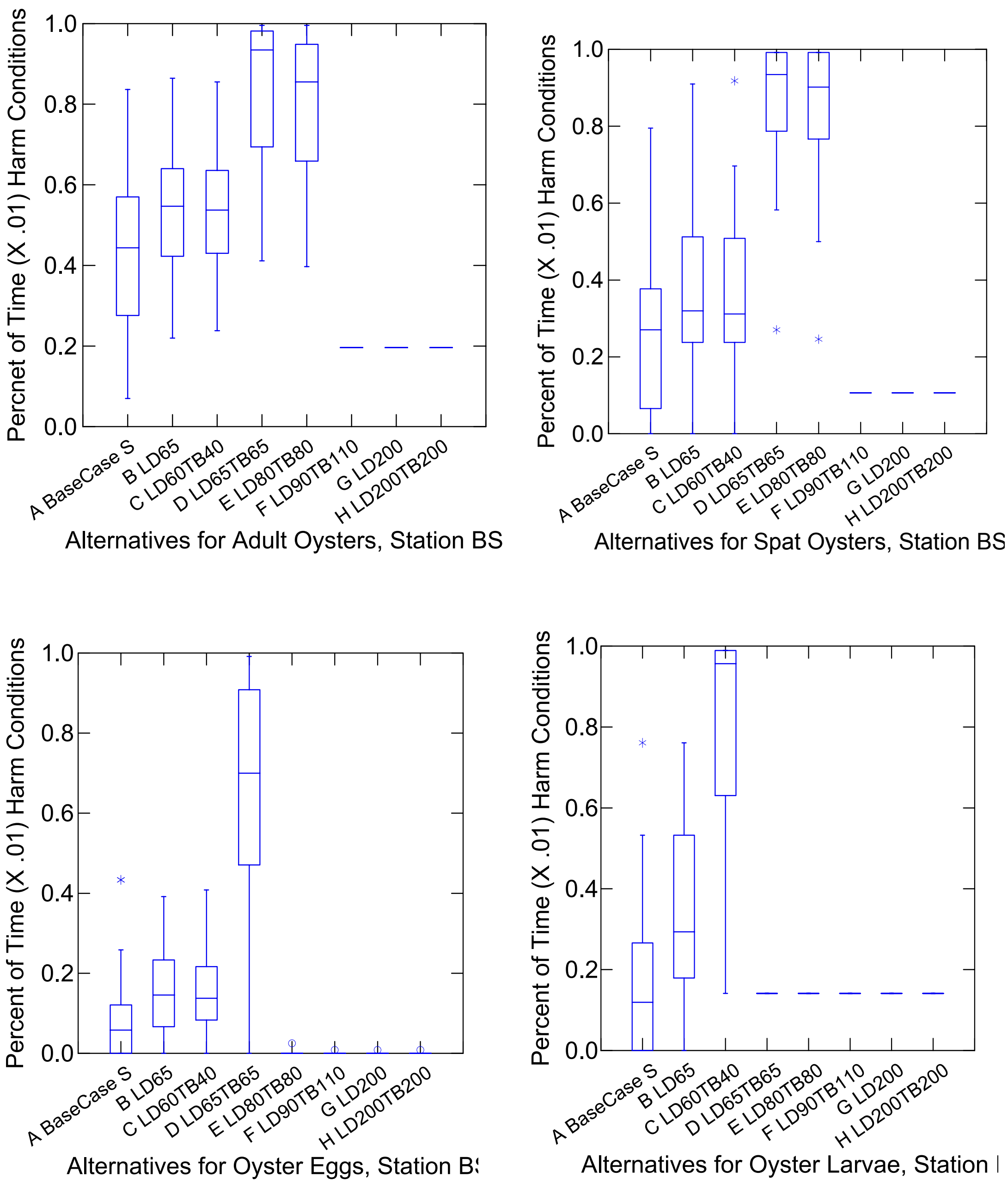


Figure 7-16. Box and Whisker Distribution Plots of the Predicted Percent of Time Harm Conditions Existed for Adults, Spat, Larvae, and Eggs in the BASE Case and Seven Constant Flow Scenarios at Boy Scout Dock (Station BS, RM 5.92).

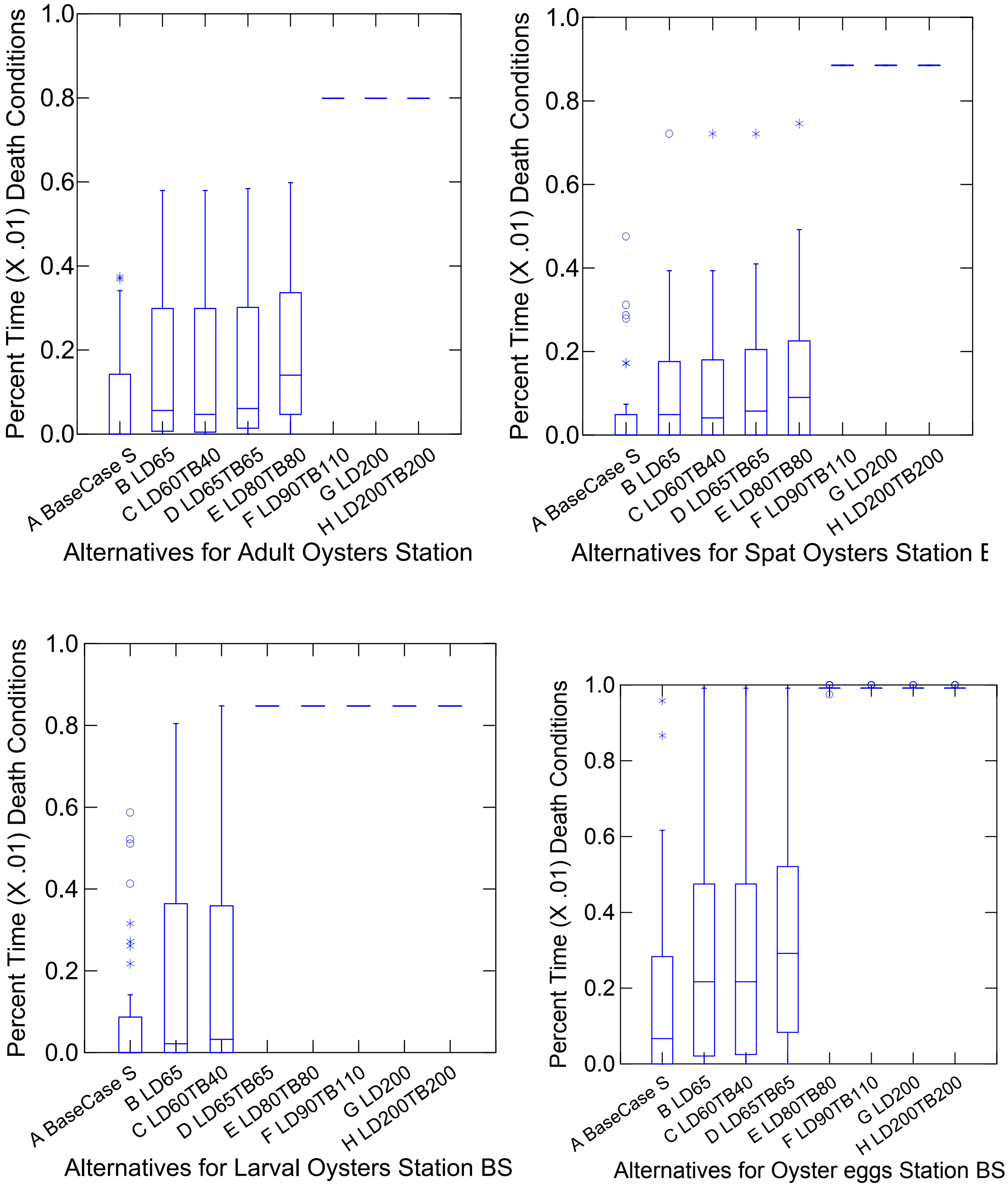


Figure 7-17. Box and Whisker Distribution Plots of the Predicted Percent of Time Death Conditions Existed for Adults, Spat, Larvae, and Eggs in the BASE Case and Seven Constant Flow Scenarios at Boy Scout Dock (Station BS, RM 5.92).

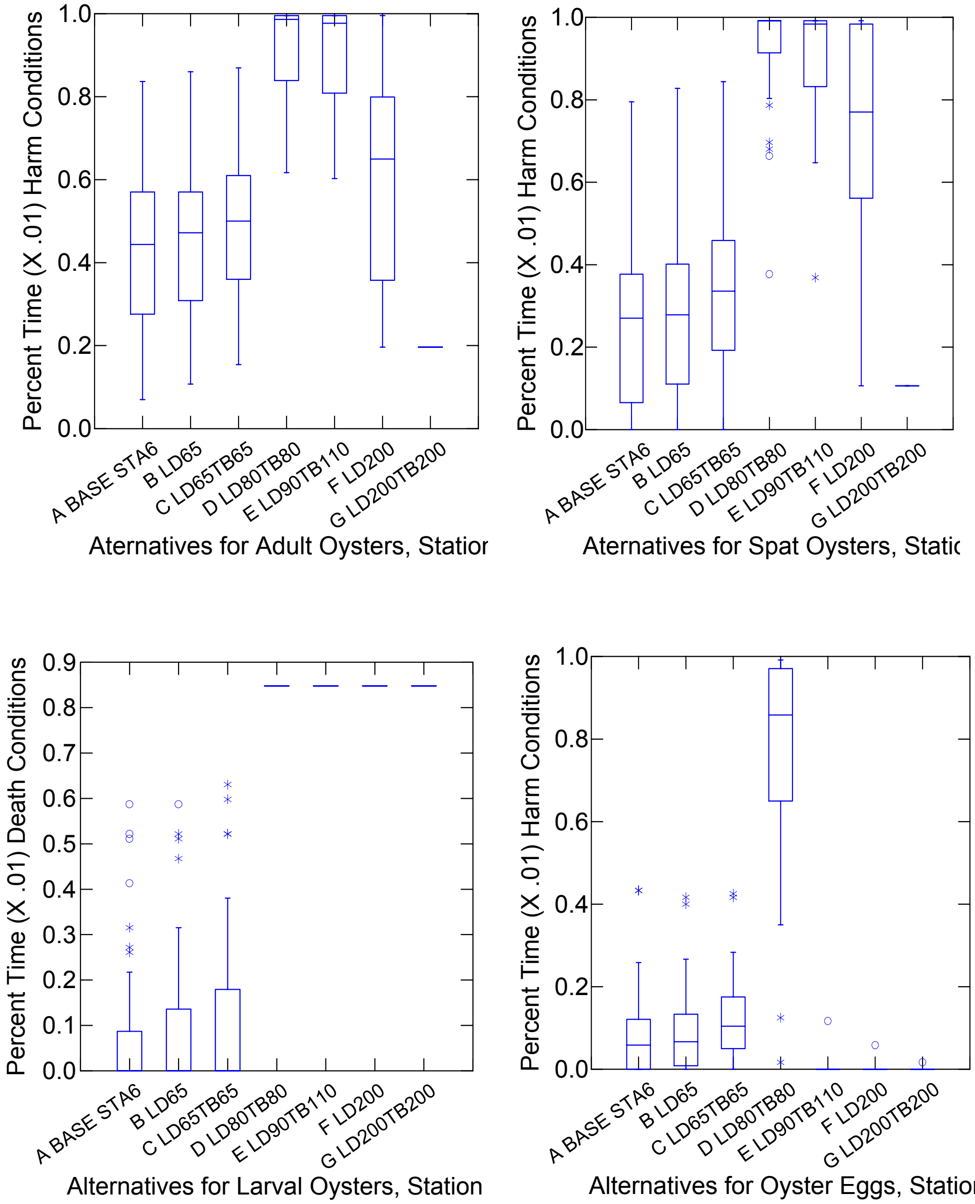


Figure 7-18. Box and Whisker Distribution Plots of the Predicted Percent of Time Harm Conditions Existed for Adults, Spat, Larvae, and Eggs in the BASE Case and Six Constant Flow Scenarios at Station 6, RM 5.45.

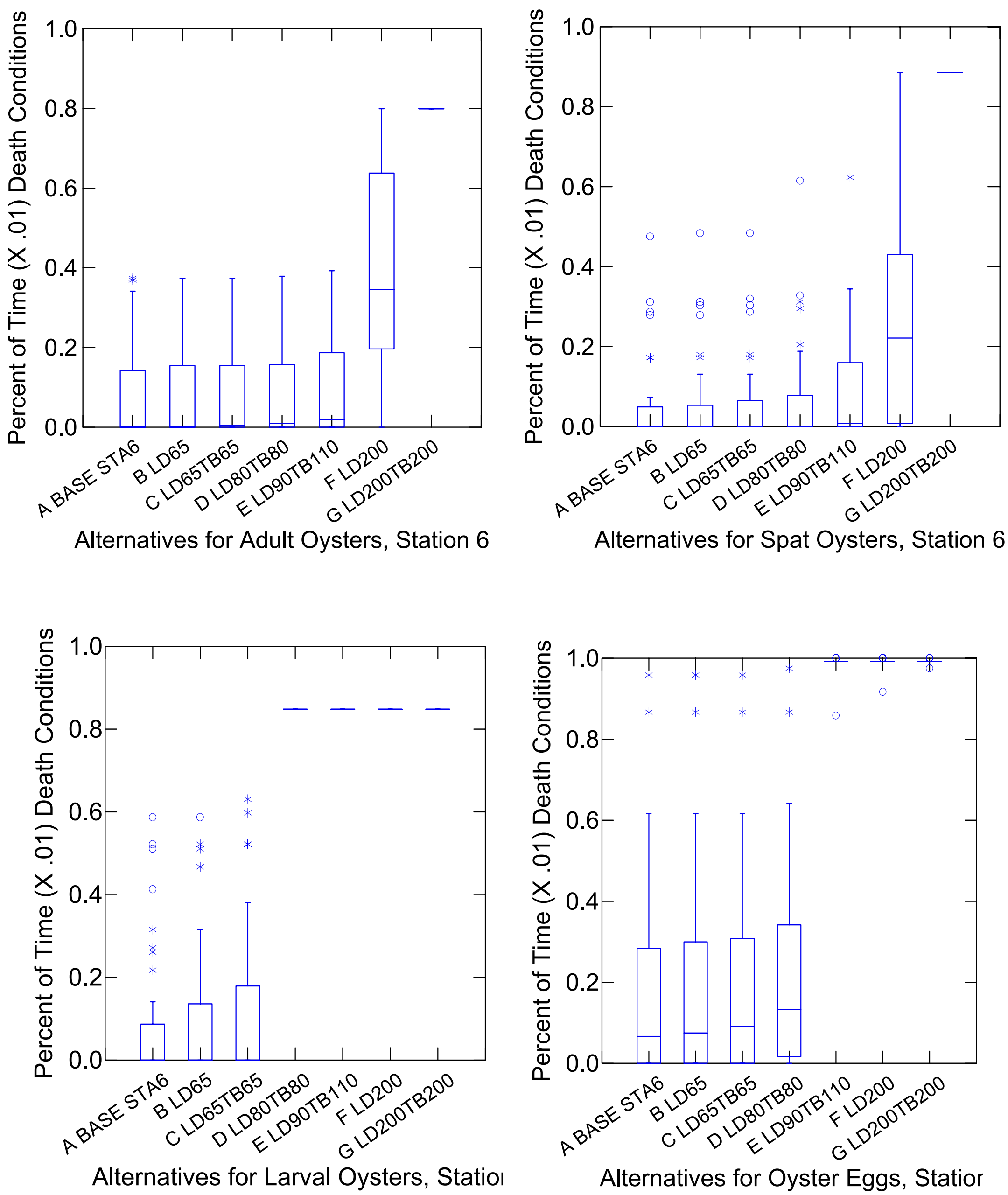


Figure 7-19. Box and Whisker Distribution Plots of the Predicted Percent of Time Death Conditions Existed for Adults, Spat, Larvae, and Eggs in the BASE Case and Six Constant Flow Scenarios at Station 6, RM 5.45.

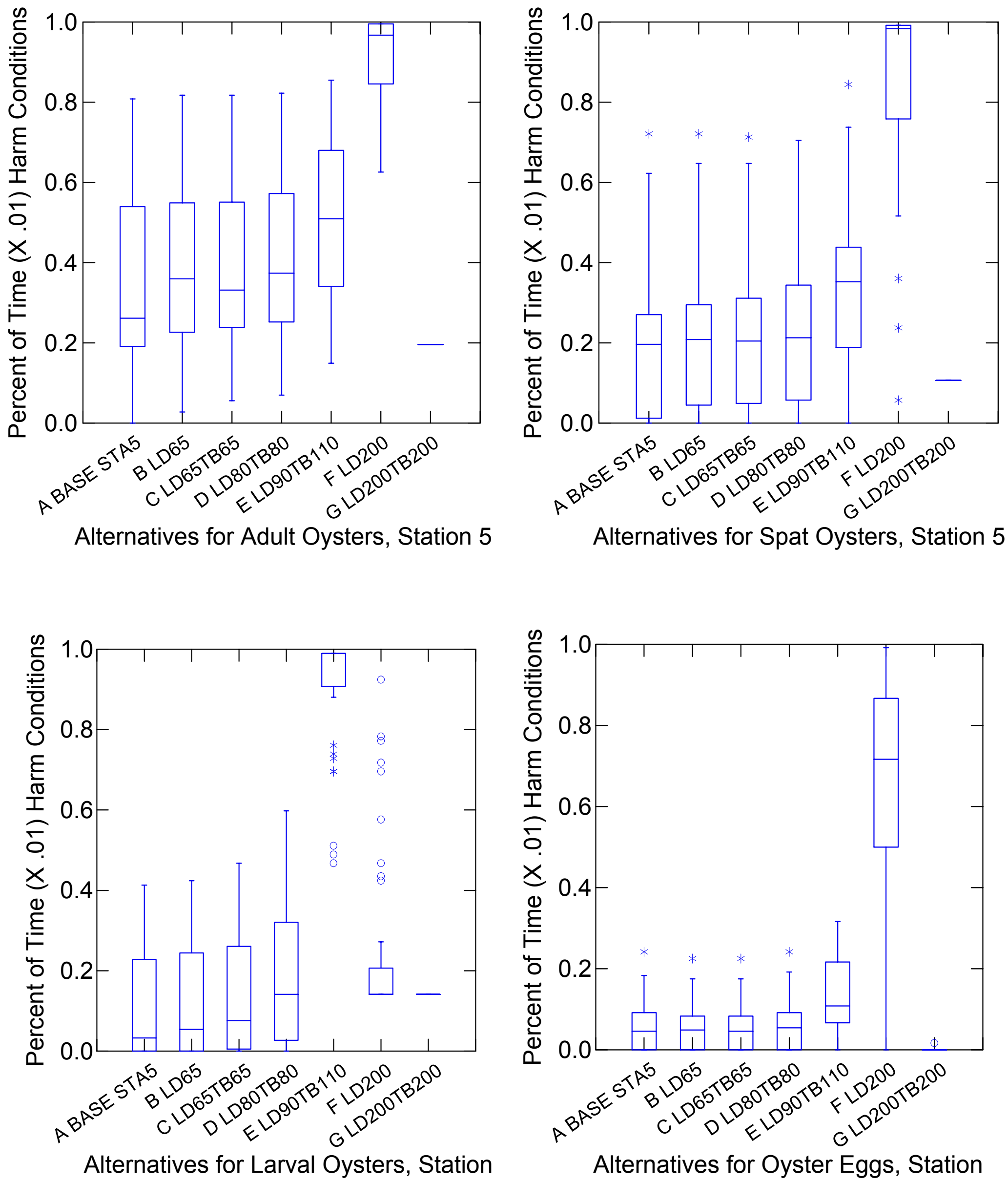


Figure 7-20. Box and Whisker Distribution Plots of the Predicted Percent of Time Harm Conditions Existed for Adults, Spat, Larvae, and Eggs in the BASE Case and Six Constant Flow Scenarios at Station 5, RM 4.93.

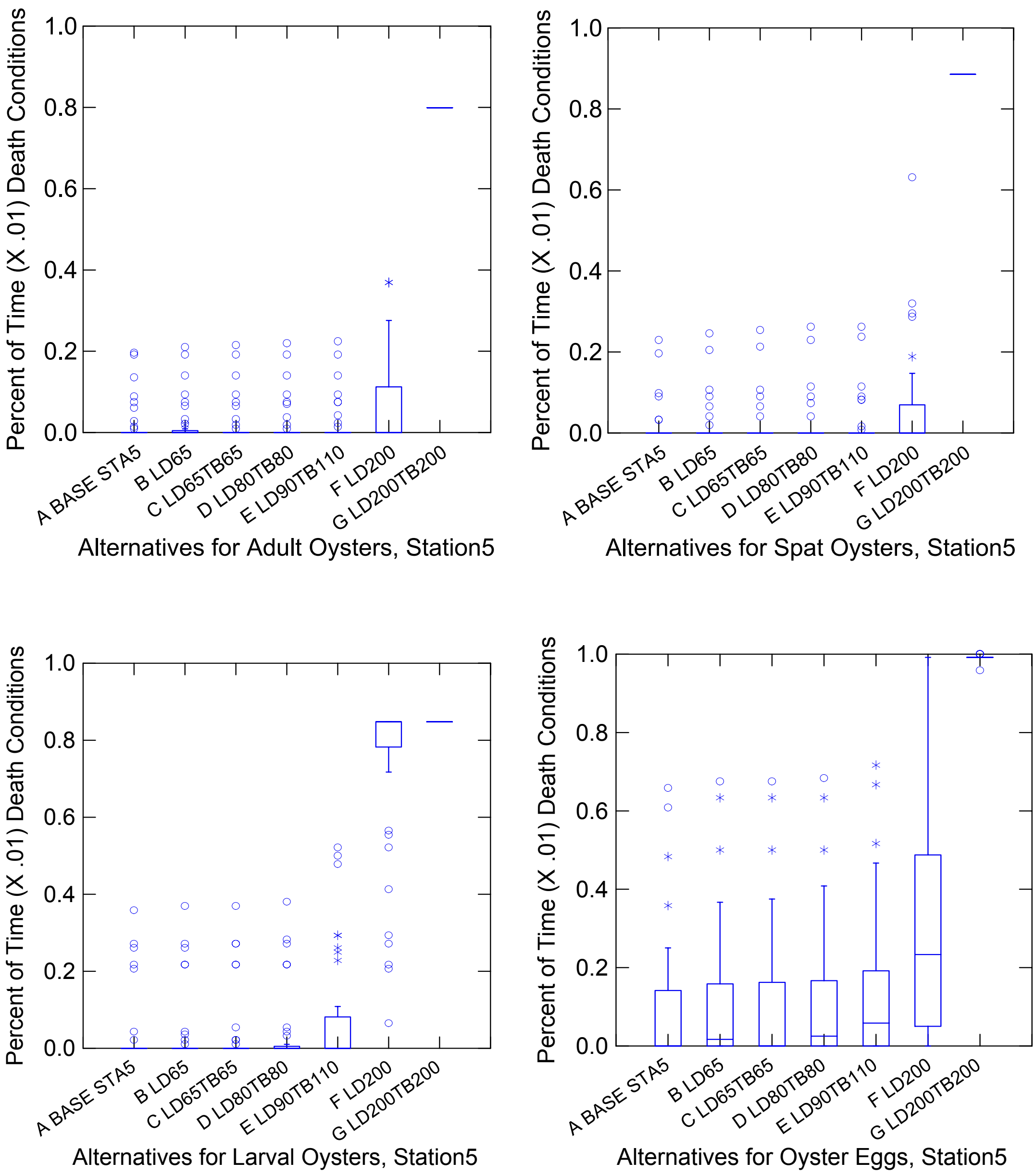


Figure 7-21. Box and Whisker Distribution Plots of the Predicted Percent of Time Death Conditions Existed for Adults, Spat, Larvae, and Eggs in the BASE Case and Six Constant Flow Scenarios at Station 5, RM 4.93.

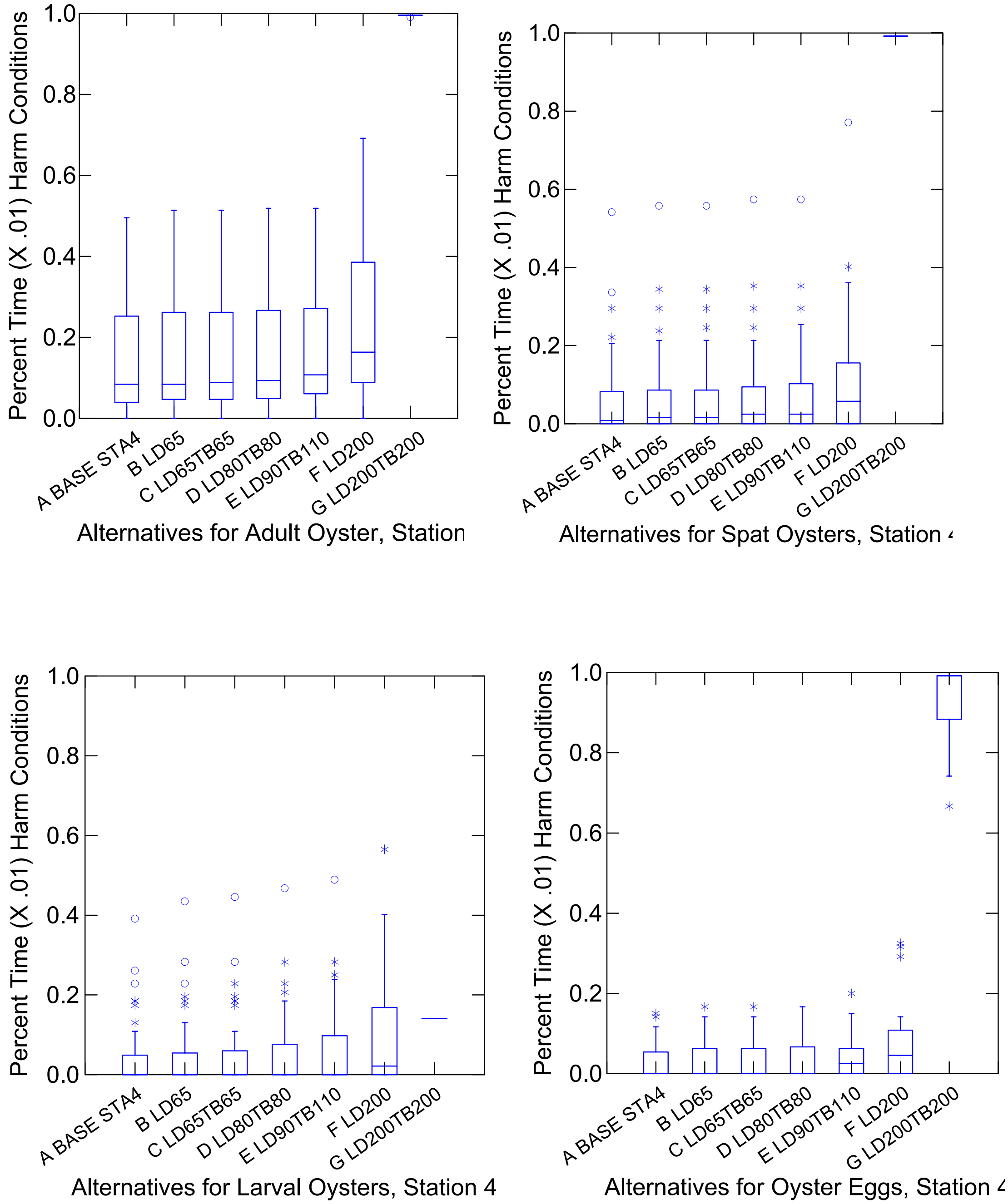


Figure 7-22. Box and Whisker Distribution Plots of the Predicted Percent of Time Harm Conditions Existed for Adults, Spat, Larvae, and Eggs in the BASE Case and Six Constant Flow Scenarios at Station 4, RM 4.13.

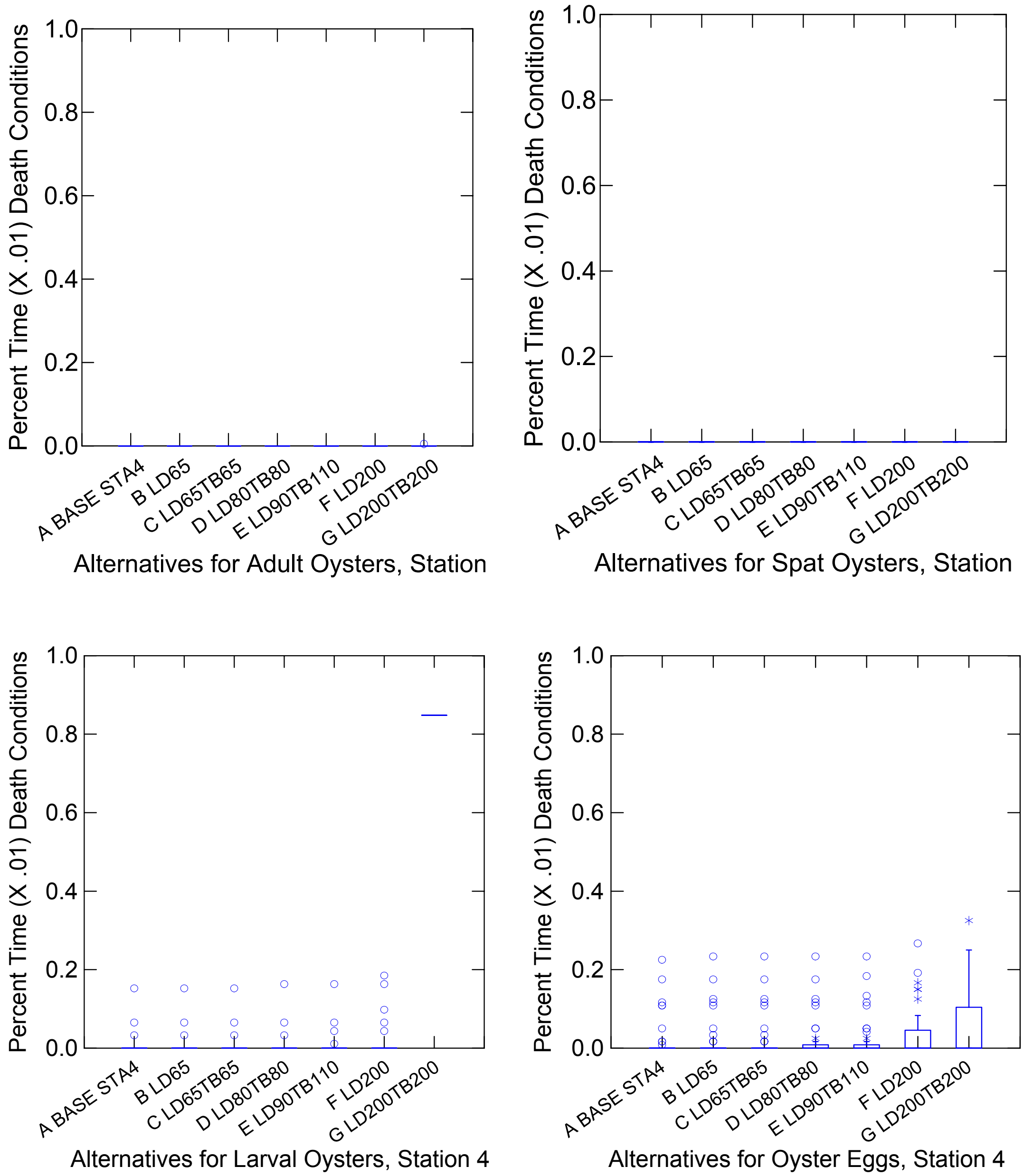


Figure 7-23. Box and Whisker Distribution Plots of the Predicted Percent of Time Death Conditions Existed for Adults, Spat, Larvae, and Eggs in the BASE Case and Six Constant Flow Scenarios at Station 4, RM 4.13.

The overall results of both the visual and BWP analyses of the four oyster growth stages in terms of "Death" and "Harm" stress categories are summarized in **Table 7-14.** The "Harm" category in the table is "bolded" to highlight the critical flow scenarios. The critical constant flow (combined flows from Lainhart Dam and other tributaries) to avoid significant stress and harm to oyster resources is 90 cfs for Boy Scout station (RM 5.92), 130 cfs for Station 6 (RM 5.45), 160 cfs for Station 5 (RM 4.93) and 230 cfs for Station 4 (RM 4.13).

Table 7-14. Summary of Oyster Death and Harm Stress Categories for Each Growth Stage at the Four Oyster Sites.

Station (River Mile)	**Adult Death**	**Spat Death**	**Larvae Death**	**Egg Death**	**Recommended Scenario (Maximum Flow)**
BS (RM 5.92)	LD65LD65	LD65LD65	LD60TB40	LD60TB40	LD60TB40 (~100 cfs)
Station 6 (RM 5.45)	LD90TB110	LD80TB80	LD65TB65	LD80TB80	LD65TB65 (~130 cfs)
Station 5 (RM 4.93)	LD90TB110	LD90TB110	LD90TB110	LD90TB110	LD90TB110 (~200 cfs)
Station 4 (RM 4.25)	LD200TB200	LD200TB200	LD200	LD200	LD200 (~230 cfs)
	Adult Stress/Harm	**Spat Harm**	**Larvae Harm**	**Egg Harm**	
BS (RM 5.92)	**LD60TB40**	**LD60TB40**	**LD65**	**LD60TB40**	**LD65 (~90 cfs)**
Station 6 (RM 5.45)	**LD65TB65**	**LD65TB65**	**LD65TB65**	**LD65TB65**	**LD65TB65 (~130 cfs)**
Station 5 (RM 4.93)	**LD80TB80**	**LD80TB80**	**LD80TB80**	**LD80TB80**	**LD80TB80 (~160 cfs)**
Station 4 (RM 4.25)	**LD200**	**LD200**	**LD200**	**LD200**	**LD200 (~230 cfs)**

EVALUATION OF POLYHALINE ZONE: SEAGRASSES

Evaluation Methods

The purpose of this section is to describe methods used to evaluate whether increases in upstream flows could impact downstream seagrass resources. This evaluation is based on the results of salinity model runs and the seagrass salinity performance measures presented in **Chapter 4**. This evaluation focuses only on potential impacts on seagrasses from changes in salinity. However, other factors (particularly water quality parameters which impact light availability) are clearly important in understanding potential impacts to seagrasses. As restoration efforts move from the planning stage to more specific design phases it may be necessary to develop more comprehensive methods for evaluating potential impacts to seagrasses.

The first step in this preliminary evaluation of potential impacts to seagrasses was to identify areas of the estuary where seagrasses occur and should be protected. Based on the data presented in **Chapter 4**, seagrass beds extend upstream to approximately RM 3.4. Accordingly, the “seagrass protection zone” for this plan includes all areas of the estuary downstream of approximately RM 3.4. The next step in the evaluation was to identify modeled salinity sites that would represent the range of salinity within the “seagrass protection zone.” Five modeled salinity sites were identified: 1) Coast Guard Station (RM 0.70); 2) North Bay (RM 1.48); 3) Sand Bar (RM 1.74); 4) Pennock Point (RM 2.44); and 5) Site O2 (RM 3.26, nearest station to RM 3.4).

At each of the five sites, results of six constant flow model runs (**BASE**, **LD65**, **LD65TB65**, **LD90TB110**, **LD200**, and **LD200TB200**) were compared by determining the total number of days within the 39-year modeling period (January 1, 1965 – December 30, 2003) that fell within each of the seagrass performance measure “stress” categories presented in **Table 4-5**, **Chapter 4**. Model runs that simulated the “base” conditions indicated no impacts to seagrass resources beyond those experienced under existing salinity conditions. Model runs that had more days that fell within the “potential stress” and “stress” categories than existing conditions were considered less desirable than existing conditions and potentially detrimental to the seagrass resources.

To determine appropriate performance measures to use for each site, the seagrass species map (see **Chapter 4, Figure 4-10**) was used to identify one key seagrass species for each modeled salinity site. Since turtle grass (*Thallasia testudinum*) is found upstream to the North Bay site, salinity performance measures for this species were used for the Coast Guard and North Bay sites. The upstream limit of manatee grass (*Syringodium filiforme*) is currently the Sand Bar location, so manatee grass salinity performance measures were used for this site. For the remaining two locations, shoal grass (*Halodule wrightii*), the dominant species at these sites, was used as the key species. Because Johnson’s seagrass (*Halophila johnsonii*), a threatened species, was found at all five locations during the summer of 2004, a second evaluation of the data was conducted using the salinity performance measures for Johnson’s seagrass at all five locations.

Another analysis was conducted using the performance measures presented in **Table 4-6, Chapter 4**. These performance measures were based on literature salinity tolerance values that included duration of a salinity threshold associated with a severe stress event (such as blade mortality). The data were evaluated for each site and each model run to determine how many “stress” events occurred over the 39-year period of record. If a stress event occurred then it was assumed that the seagrass did not recover until the next growing season (March of the following year). Model runs with more stress events than existing conditions were considered less desirable than existing conditions and potentially detrimental to the seagrass resources. The same key species used for the above evaluations were used for this evaluation. The “stress” performance measures for Johnson’s seagrass were also evaluated at all five sites.

These frequency evaluations were also conducted on data sets for a recent wet year (1995) and a recent dry year (2000). This evaluation was geared to understand the shorter term impacts associated with wet or dry conditions. The same key species used for the 39-year evaluation were also used for this analysis. As for the 39-year evaluation, the performance measures for Johnson's seagrass were also evaluated at all five sites.

The results of these evaluations were compared to identify which model runs produced salinity conditions similar to existing conditions and which runs resulted in more seagrass "potential stress" and "stress" than existing conditions.

Results and Discussion

Long-term (39-Year) Data Evaluation:

Predicted salinities for six model runs, for a 39-year period, were compared to the salinity tolerances of key seagrass species (see **Chapter 4**, **Table 4-5**) at five locations along a salinity gradient in the Loxahatchee Estuary. The results are summarized in **Figure 7-24**. At the three downstream locations (Coast Guard at RM 0.70, North Bay at RM 1.48 and Sand Bar at RM 1.74), model results were similar per site; conditions were optimal for the key seagrass species all or most of the time for all model runs. When conditions were not optimal, these less desirable conditions were experienced similarly across model runs.

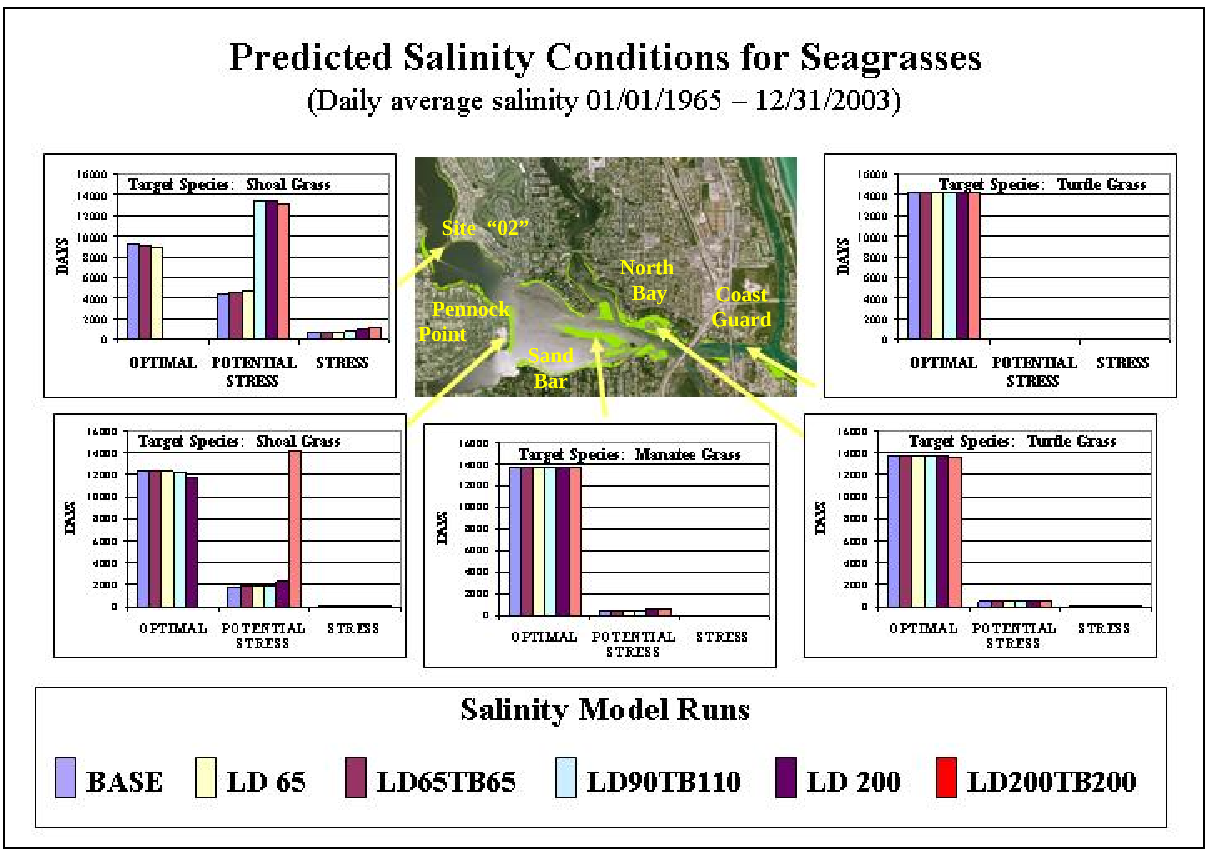


Figure 7-24. Predicted Salinity Conditions for Key Seagrasses at Five Locations Within the Polyhaline Ecozone.

At the Pennock Point (RM 2.44) location, results of the highest flow model run (**LD200TB200**) differed from all other model runs. There were no "optimal" days for shoal grass and the number of "potential stress" days was substantially higher than for all other model runs. At the most upstream seagrass location (Site O2 at RM 3.26), results of the three highest flow model runs (**LD90TB110, LD200,** and **LD200TB200**) had considerably more "potential stress" days for shoal grass than all other model results. Additionally, no "optimal" days occurred for these three model runs. Model runs **LD65** and **LD65TB65** were similar to base conditions at all five locations.

Since Johnson's seagrass was found throughout the estuary in 2004, the same evaluation was done for this threatened species at all five locations. Results (**Figure 7-25**) were similar to those observed in **Figure 7-24**. The **BASE**, **LD65**, and **LD65TB65** model results were similar at all five locations. The highest flow model run, **LD200TB200**, was different from all other model runs at the Pennock Point (RM 2.44) location; with no "optimal days" for Johnson's seagrass and substantially more "potential stress" days than all other model runs. Additionally, the **LD90TB110, LD200**, and **LD200TB200** had considerably more "potential stress" days at Site O2 than all other model runs.

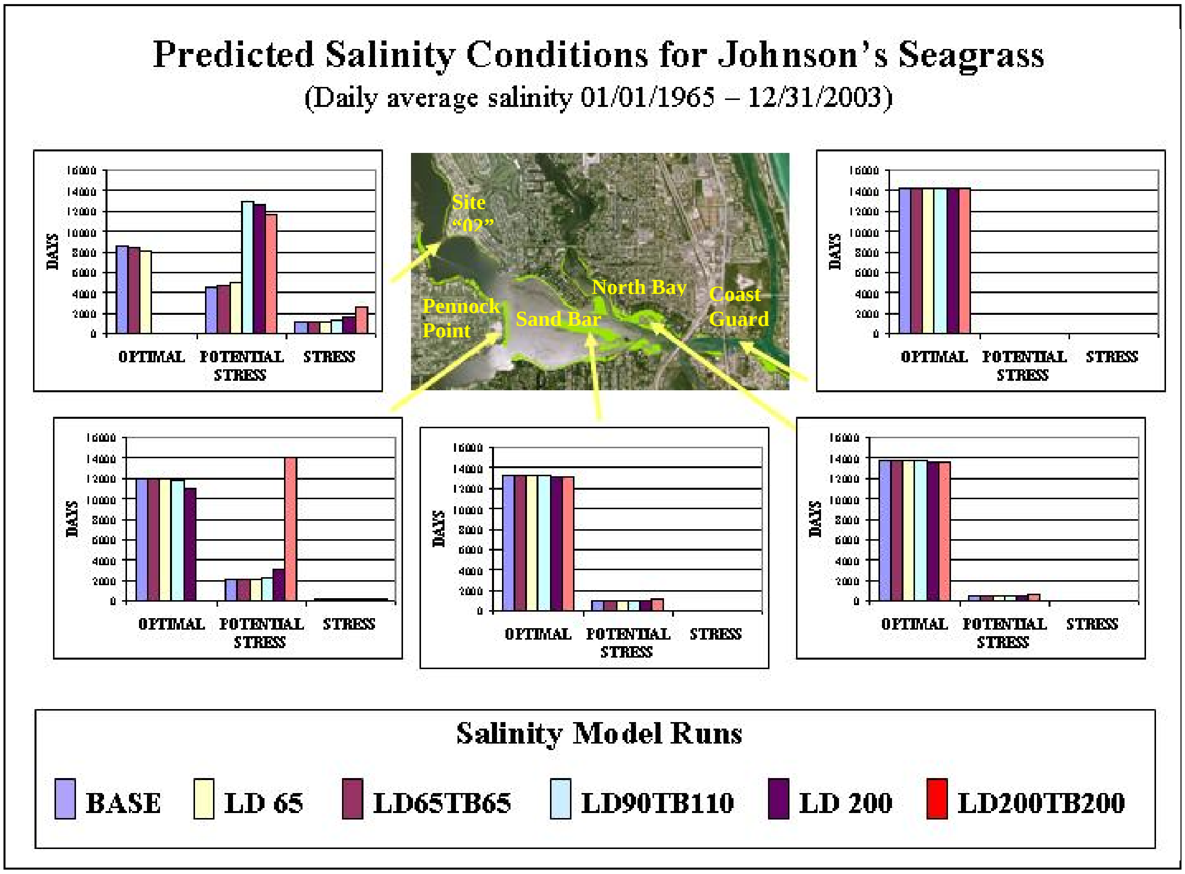


Figure 7-25. Predicted Salinity Conditions for Johnson's Seagrass at Five Locations Within the Polyhaline Ecozone.

Despite clear differences in model runs at the upstream locations, the number of "stress" days for all model runs at all sites were similar, with a small increase above the base run for model runs **LD200** and **LD200TB200** at Site O2 (RM 3.26). These differences were more pronounced for Johnson's seagrass than for shoal grass, but were still relatively small.

The 39-year data set was further evaluated for each location and each model run using the performance measures presented in **Table 4-6** for the "Stress" category. These performance measures were based on limited literature salinity tolerance values that included duration of a salinity threshold associated with a stress event (such as blade mortality). The total numbers of stress events per model run per location are summarized in **Table 7-15**. There were no differences between the number of "stress events" for any of the model runs at any of the sites. Only one stress event was noted and it occurred at Site O2 (RM 3.26) for Johnson's seagrass for all model runs in October 1995. This result is consistent with **Figures 7-24** and **7-25** which indicate that significant stress is unlikely for that model runs.

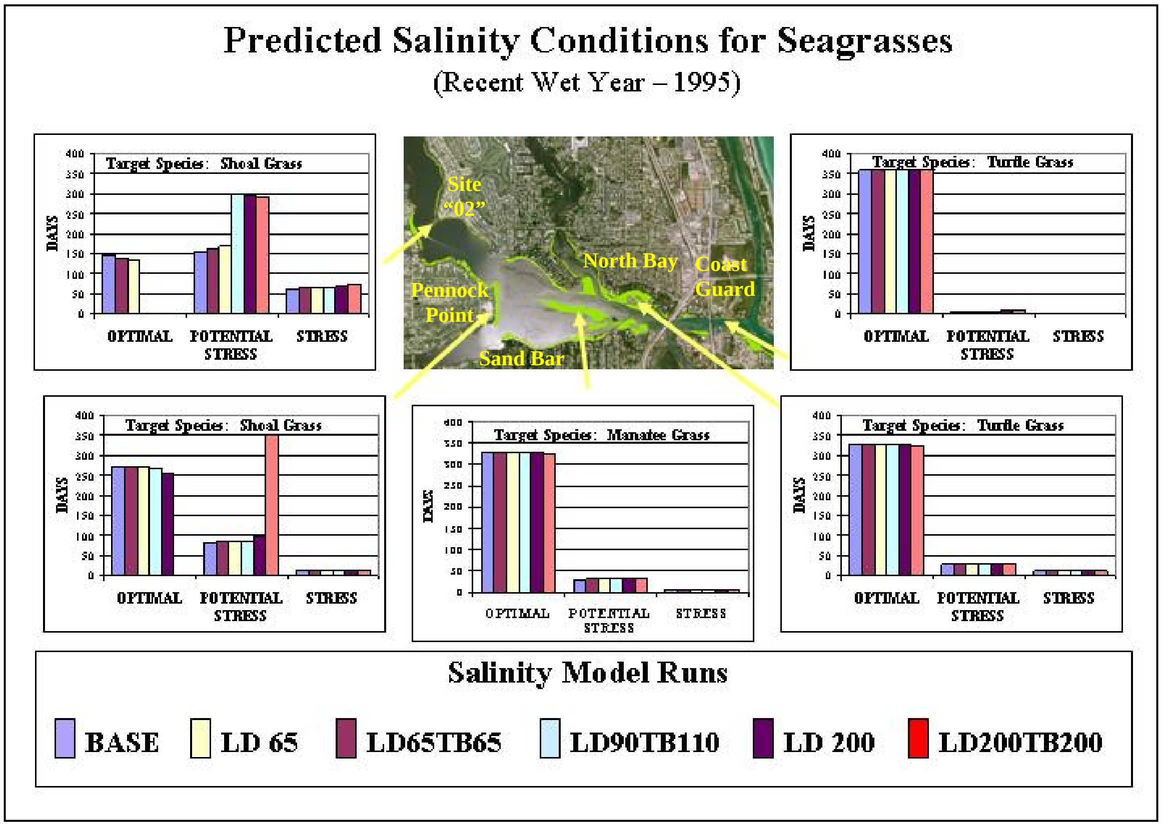
Table 7-15. Number of Stress Events per Model Run Based on Daily Average Salinity from 1/1/1965 – 12/30/2003.

Location	Target Seagrass Species	Stress Event (Salinity/Duration[a] Threshold)*	Number of Stress Events Per Model Run					
			BASE	LD 65	LD65TB65	LD90TB110	LD 200	LD200TB200
Coast Guard RM 0.70	Turtle grass	≤ 4 ppt for 7 days	0	0	0	0	0	0
	Johnson's seagrass	≤ 5 ppt for 3 days	0	0	0	0	0	0
North Bay RM 1.48	Turtle grass	≤ 3.5 ppt for 21 days	0	0	0	0	0	0
	Johnson's seagrass	≤ 5 ppt for 3 days	0	0	0	0	0	0
Sand Bar RM 1.74	Manatee grass	≤ 15 ppt for 26 days	0	0	0	0	0	0
	Johnson's seagrass	≤ 5 ppt for 3 days	0	0	0	0	0	0
Pennock Point RM 2.44	Shoal grass	≤ 5 ppt for 30 days	0	0	0	0	0	0
	Shoal grass	≤ 3.5 ppt for 21 days	0	0	0	0	0	0
Site O2 RM 3.26	Shoal grass	≤ 5 ppt for 30 days	0	0	0	0	0	0
	Shoal grass	≤ 3.5 ppt for 21 days	0	0	0	0	0	0
	Johnson's seagrass	≤ 5 ppt for 3 days	1	1	1	1	1	1

[a] The duration in this evaluation is in consecutive days.

Short-term (Wet vs. Dry Year) Data Evaluation:

Shorter term data sets were also evaluated. One recent wet year and one recent dry year were selected for this evaluation. The wet year selected was 1995 (the year when all model results showed a "stress event" at Site O2, RM 3.26) and the recent dry year selected was 2000 (**Figure 7-26**).



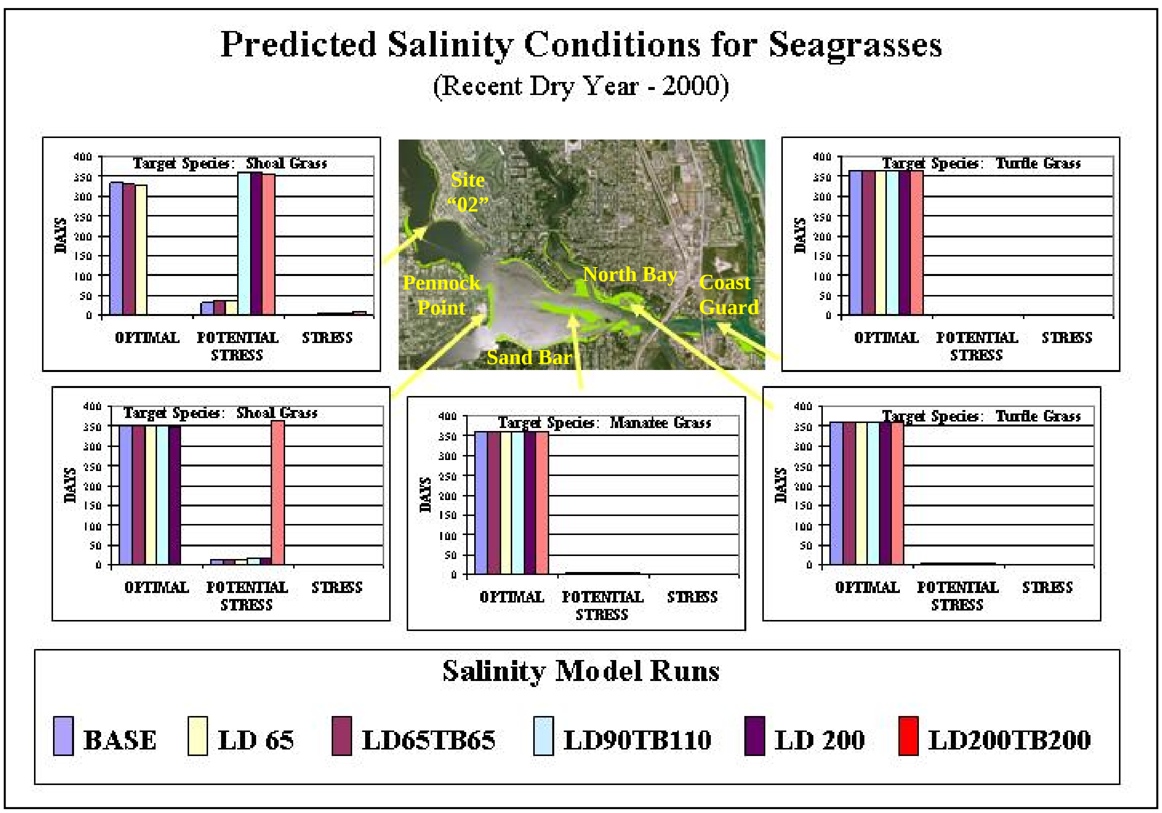


Figure 7-26. Predicted Salinity Conditions for Key Seagrasses at Five Locations Within the Polyhaline Ecozone During a Recent Wet (1995) and Dry Year (2000).

More “potential stress” and “stress” days were noted in the wet year than in the dry year (**Figure 7-26**). However, as observed for the 39-year data set, the number of “stress” days was similar across model runs at all sites for both wet and dry years. The general trends discussed above, were also observed in both wet and dry years. Model runs at the three downstream stations were similar per site in both the wet and dry year. At Pennock Point (RM 2.44) the highest flow model run became distinctly different from all other model runs in both the wet and dry years. No “optimal” days occurred and the number of “potential stress” days was greater than for all other model runs. At Site O2, the three highest flow model results were distinctly different from the base, **LD65**, and **LD65TB65** model results for both the wet and dry year (just as observed for the 39-year data set). Similar results were observed when the wet/dry year evaluation was conducted for Johnson’s seagrass (**Figure 7-27**).

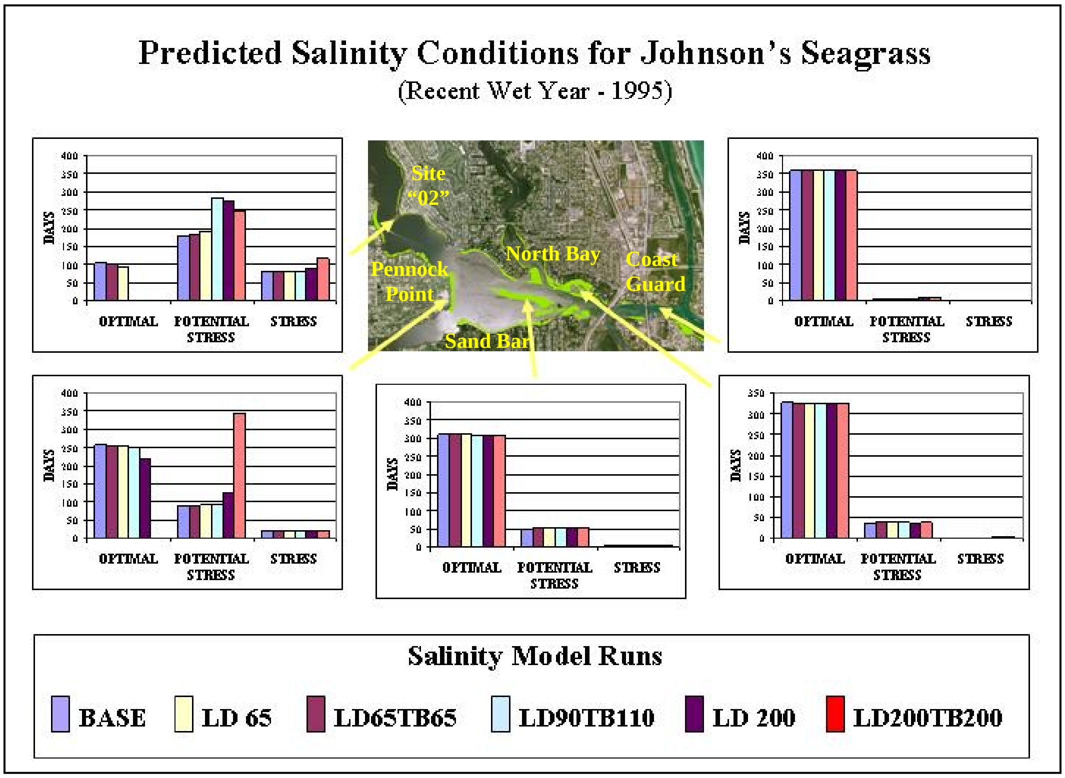
To further evaluate the wet/dry year data, daily average salinities were plotted for three of the seagrass stations Coast Guard (RM 0.70), Sand Bar (RM 1.74), and Site O2 (RM 3.26); **Figure 7-28**). In general, greater differences between model run results at a given location occurred during the dry year than during the wet year. As expected, there were more days of salinities below “optimal” conditions for seagrasses in the wet year than during the dry year. Additionally, periods of lowest salinities were similar for all model runs in both the wet and dry years.

At the Coast Guard Station (RM 0.70), salinities were optimal for seagrasses the entire dry year and much of the wet year (salinities never fell below 20 ppt in the wet year for any model run). This supports above results that indicate salinity conditions are good for seagrasses under all model scenarios at the Coast Guard Station. This area includes the “critical habitat” for Johnson’s seagrass.

At the Sand Bar (RM 1.74) location, all model runs were similar during the wet year. During the dry year, **LD200TB200** results were different (lower salinities) than all other model runs, but the results remained within optimal conditions for approximately the same number of days as all other runs. These results indicate that existing seagrass resources at the Sand Bar location would not be adversely impacted by any of the proposed flows.

At Site O2 (RM 3.26), model run **LD200TB200** results were distinctly different from all other model runs. In both the wet and dry years salinities produced by this model run were near or within stressful salinity ranges for seagrass most of the time. This supports previous results that this flow level would be unlikely to support healthy seagrass beds at Site O2. Results of model runs **LD90TB110** and **LD200** were more similar to the base run in the wet year than in the dry year. Although these two runs produce “potential stress” day counts similar to **LD200TB200** (**Figures 7-26** and **7-27**), salinities were often 8 ppt or higher than **LD200TB200** results. Due to the higher salinities associated with model runs **LD90TB110** and **LD200**, seagrass impacts should not be as great under these scenarios as they would be for the **LD200TB200** flows.

In summary, flows associated with **LD200TB200** are substantially different from the base case conditions at Pennock Point (RM 2.44). This difference is even greater at Site O2 (RM 3.26). Model runs **LD65** and **LD65TB65** produce results similar to base conditions at all seagrass locations and are not expected to impact seagrasses beyond impacts currently experienced. Model runs **LD90TB110** and **LD200** are similar to base conditions at the four downstream locations, but begin to diverge from base conditions at Site O2. These differences could potentially impact seagrass resources.



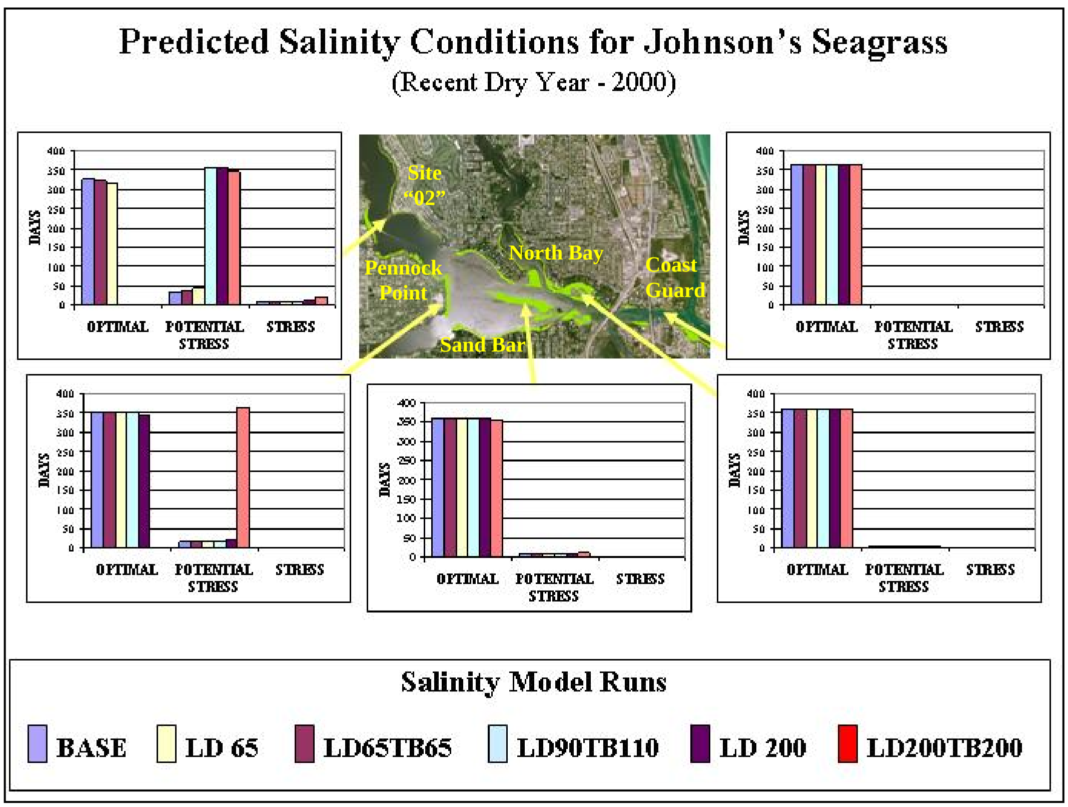


Figure 7-27. Predicted Salinity Conditions for Johnson's Seagrass at Five Locations Within the Polyhaline Ecozone During a Recent Wet (1995) and Dry Year (2000).

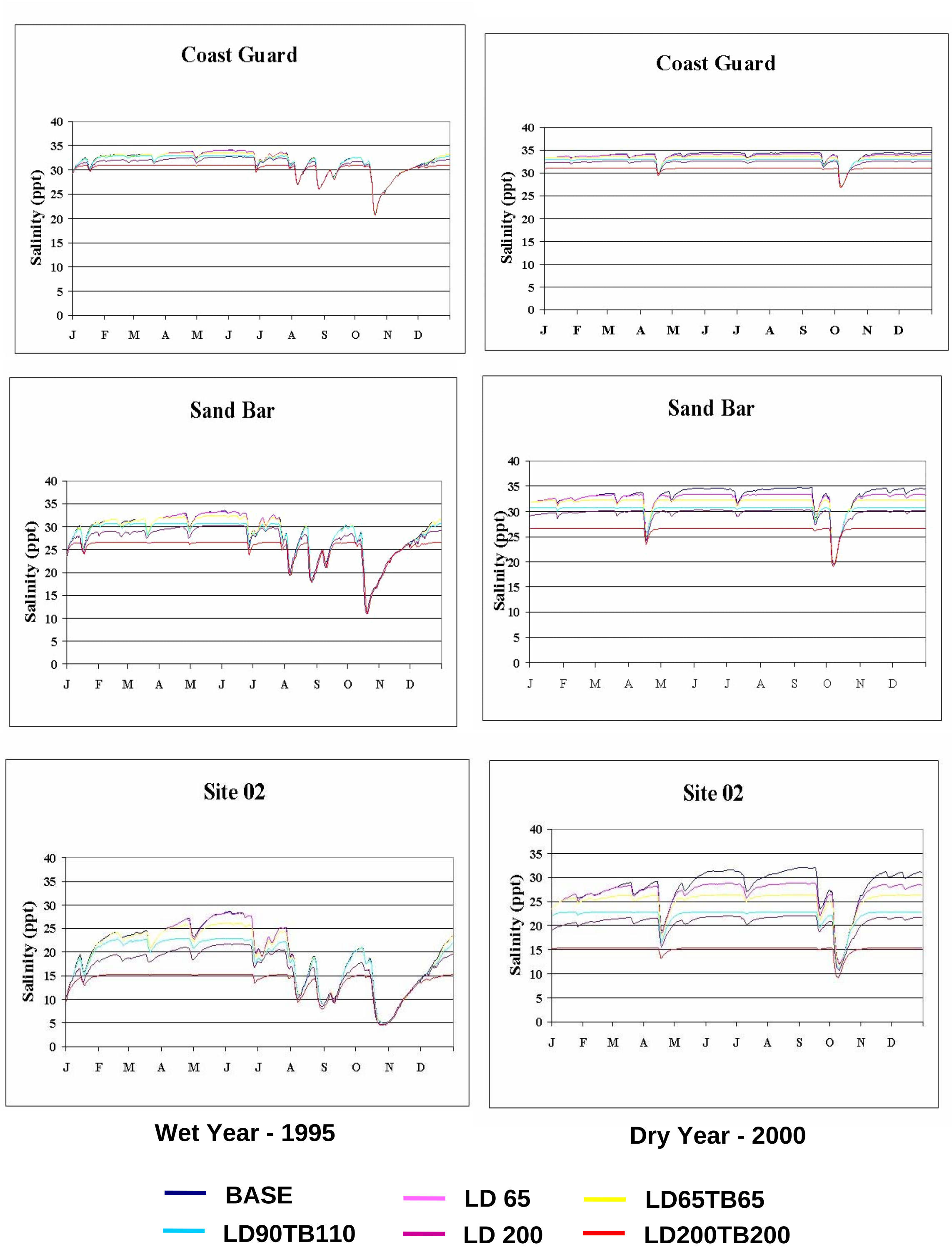


Figure 7-28. Comparison of Daily Average Salinity Conditions at Three Seagrass Locations for a Recent Wet Year (1995) and a Recent Dry Year (2000).

SUMMARY AND CONCLUSIONS

The Loxahatchee Watershed Model (WaSh) and the Loxahatchee Long-Term Salinity Management Model (LSMM) were used to simulate a 39-year (from 1965 through 2003) flow and salinity for the **BASE** condition and five flow scenarios, representing different flow augmentations for restoration. For each segment of the ecosystem including the riverine freshwater floodplain, tidal floodplain, low salinity zone, mesohaline zone, and polyhaline zone, the ecological benefit or impact is evaluated according to the VECs and PMs established in **Chapter 4**. An overall summary of the evaluation is presented in **Table 7-16** which considers all the VEC components in the Northwest Fork and the Loxahatchee Estuary. A semi-quantitative score system consisting of "+, -, and 0" signs is assigned. A "+" sign represents a positive habitat benefit while the "-"sign indicates that the scenario will result in a negative impact for a particular VEC. The **BASE** case is represented with the "0" sign. The relative significance of an impact or benefit within an eco-zone is represented by the number of "- or +" signs. Note that such comparisons are valid only within a component of VECs, and one should not equate a benefit or impact of a VEC with that of another.

In the riverine freshwater floodplain, the relationship between flow from the Lainhart Dam and the stage in the river and floodplain were established through survey and field measurements. Transects 1 (RM 14.50) and 3 (RM 12.07) were selected for evaluation in this chapter. The elevation of swamp and hydric hammock in these transects were surveyed in the field, and their hydroperiod requirements were compared with each of the flow scenarios. The scenarios of **LD65, LD65TB65**, and **LD90TB110** provide a flow significantly higher than for the **BASE** condition, particularly in the dry season. Improvement in the wet season inundation requirement of **LD65** and **LD65TB65** is not as significant as for **LD90TB110**. The hydroperiod of the hydric hammock areas is provided by severe storms with a flow from the Lainhart Dam ranging from about 190 cfs to over 300 cfs. Thus, none of the three previously described scenarios influence the hydroperiod of the hydric hammock areas. However, the scenarios of **LD200** and **LD200TB200** would impose significant adverse impacts on the hydroperiod requirements for both the riverine freshwater swamp and hydric hammock areas.

The characteristic salinity regime as defined by *Ds/Db* ratio using 1 ppt as the critical salinity standard is calculated using salinity data at four locations in the tidal floodplain of the Northwest Fork for all scenarios. Our evaluation shows that a restoration flow (Lainhart Dam plus other tributaries) in the range of 130 cfs (**LD65TB65**) to 200 cfs (**LD90TB110**) is required to provide sufficient freshwater to support riverine freshwater floodplain vegetation down to the mouth of Kitching Creek (RM 8.13). A combined flow of greater than 400 cfs would be required to provide freshwater conditions to the edge of Jonathan Dickinson State Park (RM 6). However, a flow at this high level may likely impose significant adverse impacts such as over-extended hydroperiod for the riverine freshwater floodplain and an erosion hazard in riverbed.

Evaluation of the LSZ employs a different methodology from the other VECs because a mobile organism (zooplankton) is being used as the indicator in contrast to all the other VECs that are sessile. A field study was conducted along with an examination of a family of salinity curves and the simulated salinity data at a fixed location close to the JDSP boundary to evaluate the scenarios. A salinity range from 2 to 8 ppt during the months between December and July when fish reproduction is active provides the highest density of fish larvae within the reach of the river upstream of the JDSP boundary (RM 6.0). An examination of the family of salinity curves and our long-term salinity data indicates that a flow about 140 cfs (slightly higher than LD65TB65) provides a salinity of 2 ppt at RM 7.2 and 8 ppt at RM 6. Flows higher than 140 cfs may likely results in alteration of the conditions favorable to fish larvae habitat in the Northwest Fork.

Table 7-16. Overall Summary of the Evaluation of Northwest Fork Ecosystem Constant Flow Restoration Scenarios.

Eco-Zone	VEC Component	Constant Flow Restoration Scenario					
		BASE	LD65	LD65TB65	LD90TB110	LD200	LD200TB200
Riverine Floodplain	Swamp	0	+	+	++	- - -	- - -
	Hydric Hammock	0	0	0	0	- - -	- - -
Tidal Floodplain	Swamp upstream RM 9	0	++	++	++	-	- -
	Swamp upstream RM 8 (Kitching Creek Station)	0	0	++	++	++	- -
	Swamp upstream RM 6.14 (VT9 Station)	0	0	0	0	+	- -
	Swamp upstream RM 5.92 (Boy Scout Dock)	0	0	0	0	0	- -
Low Salinity Zone	Fish Larvae	0	0	0	-	-	- -
Mesohaline Zone	Oysters upstream RM 5.92 (Boy Scout Dock)	0	-	- -	- - -	- - -	- - -
	Oysters upstream RM 5.45 (Station O6)	0	0	-	- -	- - -	- - -
	Oysters upstream RM 4.93 (Station O5)	0	0	0	- -	- -	- - -
	Oysters upstream RM 4.13 (Station O4)	0	0	0	-	- -	- - -
Polyhaline Zone	Seagrasses upstream RM 3.26 (Site O2)	0	0	0	- -	- -	- - -
	Seagrasses upstream RM 2.44 (Pennock Point)	0	0	0	-	-	- -
	Seagrasses upstream RM 1.74 (Sand Bar)	0	0	0	0	0	0
	Seagrasses upstream RM 1.48 (North Bay)	0	0	0	0	0	0
	Seagrasses upstream RM 0.70 (Coast Guard)	0	0	0	0	0	0

0 = No change; +, ++ = Beneficial impact; -, - - , - - - = Negative impact.

An oyster stress model was used to evaluate how the restoration scenarios influence the existing oyster bed between RM 6.0 and RM 4.0. The analysis concluded that a critical flow exists for each of the four locations evaluated to protect the downstream oyster bed. The critical flow (combined flows from Lainhart Dam and other tributaries) is 90 cfs (**LD65**) for the Boy Scout station (RM 5.92), 130 cfs (**LD65TB65**) for Station 6 (RM 5.45), 160 cfs (**LD80TB80**) for Oyster Station 5 (RM 4.93), and 230 cfs (**LD200**) for Oyster Station 4 (RM 4.13). Since one of the governing principles for the Northwest Fork restoration is that restoring one component of the ecosystem should not damage or destroy any other component, it is necessary to consider "relocating" some of the existing oyster beds to a down stream location in selecting the final restoration scheme (refer to **Figure 4-6** for the acreage of oyster beds from RM 6.0 to RM 3.7).

Evaluation of seagrass involves five sites in the embayment area of Loxahatchee Estuary. None of the scenarios creates the impact of the “Stress” category for seagrasses at any of the sites. Scenarios **LD65** and **LD65TB65** produce results similar to the **BASE** condition at all seagrass locations and are not expected to impact seagrasses beyond what is currently experienced. Scenarios **LD90TB110** and **LD200** are similar to **BASE** conditions at the four downstream locations, but begin to diverge from the **BASE** conditions at the most upstream location, Site O2 (RM 3.26), along with an increase in the number of days with low salinity of “Potential Stress.” These differences could potentially impact seagrass resources. The **LD200TB200** scenario is substantially different from the base case conditions at the Pennock Point site. This difference is even greater at Site O2 (RM 3.26).

In conclusion, our evaluation did not come up with one scenario that met all the requirements of the VECs in the ecosystem. It needs to be noted that all of the scenarios tend to reduce the variability of flows, and this could favor certain species within the communities and reduce diversity of the ecosystem. A flow pattern capturing the natural dry and wet season variability needs to be considered to maximize the ecologic benefit. **Chapter 8**, **Development of the Preferred Restoration Flow Scenario**, describes the addition of hydrologic variability in the scenario development and evaluation along with suggestions received during the public meeting process. The saltwater barrier as a potential restoration alternative is analyzed in **Chapter 9**.

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Chapter 8

Development of the Preferred Restoration Flow Scenario for the Northwest Fork

INTRODUCTION

The evaluation of the initial set of five constant flow scenarios in **Chapter 7** provides a framework to understand the affect of the various flows on downstream conditions. This restoration effort encompasses a spectrum of goals including the recovery of native species and environmental conditions in the riverine floodplain, as well as, the management of dynamic, biologically diverse communities in the tidally influenced ecosystems.

The Loxahatchee River Management Coordinating Council (LRMCC) provided a forum for a series of public meetings that were held in May and June 2005 to review the results of the constant flow scenarios and the associated benefits or impacts. The SFWMD, the FDEP, FPS and the LRD also met with environmental groups such as the Loxahatchee River Environmental Coalition and Friends of the Loxahatchee River. Through the LRMCC sponsored public review process it became apparent that any single constant flow scenario could not meet all the ecological requirements of the VECs considered. One concern is that augmenting flows to reach a designated level (e.g., 65, 90, 110, or 200 cfs) results in a significant loss of hydrologic variability (the higher the minimum flow the less variability). Because the Northwest Fork ecosystems are dynamic, each VEC requires a different range of natural variation or disturbance to maintain viability or resilience. Water flows that vary both from season to season and from year to year are needed to support plant and animal communities and to maintain natural habitat dynamics that support the survival and reproduction of species. Variability in the timing and rate of water flow strongly influences the size of native plant and animal populations and their age structures, the presence of rare or highly specialized species, the interactions of species with each other and with their environments, and many ecosystem processes. Periodic and episodic water flow patterns also influence water quality, physical habitat conditions and connections, and energy sources in aquatic ecosystems. The objective of this chapter is to incorporate hydrologic variability in the development of the preferred restoration flow scenario.

VARIABLE FLOW SCENARIOS

The following hydrologic variability criteria were considered during the development of the variable flow restoration scenarios:

1. **Base flow:** Base flows and associated water levels in the riverine floodplain between storm events determine the minimum quantity of water in the channel. These flows directly influence the amount of aquatic habitat available and the depth of saturated soil for floodplain vegetation. The goal in developing variable flow scenarios is to increase base flow to limit saltwater intrusion in the tidal floodplain while maintaining the appropriate environmental conditions in the riverine floodplain for aquatic dependant species (i.e. fish and amphibians), seed germination, vegetation communities, and wildlife.

2. **Seasonal timing of high flows**: High flows during the wet season, particularly the months of August though November, are critical for maintaining the hydroperiod of the cypress swamp in the riverine floodplain and many other native species whose reproductive success is tied to seasonal high flows. High flows can also remove species that are poorly adapted to dynamic river environments such as upland tree species. The goal in developing the variable flow scenarios is to augment flow during the wet season to maintain a minimum of 120 days of inundation for the cypress swamp in the riverine floodplain.
3. **Monthly and short-term variations in flow:** Monthly flow variability is an important factor influencing the ecosystem productivity and foodweb structure of the riverine and estuarine systems. Short-term variable base flows, unlike constant flows, also provide enhanced estuarine water quality and zooplankton communities. The goal in developing the variable flow scenarios is to maintain monthly variability and provide augmented base flows in a fashion that imitates runoff from a small rainfall event.
4. **Frequent and rare floods during the wet season:** To maintain vegetation dynamics in the Northwest Fork, moderately high flows (about 170 ~ 450 cfs over the Lainhart Dam) are needed to inundate adjacent hydric hammock plant communities within the riverine floodplain. These frequent flooding events, which occur typically with a 1- to 2-year return interval, flush fine materials from the streambed, facilitating the dispersal of organisms and promoting higher biological production during low flow periods. The success of non-native invaders is often minimized by such frequent floods. Rare or extreme events, such as 10-year storm events, transfer large amounts of sediment from the main channel to floodplain and disperse seed sources further up in the landscape thereby increasing habitat diversity along the river. The goal in developing the variable flow scenarios is to maintain the frequent and rare high floods with the same periodicity as the base condition during the 39-year period of record.

Based on these four criteria, flow augmentation over Lainhart Dam is performed with a set of logic-based rules that allows for a new times series to be generated based on the flow time series under the base condition. The logic for generating the new time series of the restoration flow is shown in **Figure 8-1**. The logic sequence starts with a series of breakpoint flows for different months of a calendar year. These breakpoint flows are 130 cfs for the months of August through November, representing the wet season, 70 cfs for February through May, representing the dry season, and 80 cfs for June, July, December, and January, which represent the transitional period. These breakpoint flows were identified through an analysis of the flow distribution under the base condition and field observation of floodplain inundation under certain flow regimes. Thus, if the daily flow in the respective month is less than the breakpoint flow for that month, flow augmentation is needed. The restoration flow will then be the same with the base condition flow.

There are two methods to determine the amount of additional flow. The method that provides a larger flow for that particular day has the priority to be applied. The first method is based on the monthly median flows in the base condition. The monthly median flows are derived by ranking all of the flows that occurred during the month throughout the 39 years. The amount of flow that needs to be added is determined by the following formula:

*(130 cfs-Monthly Median)*Monthly Median/October Median* *[8-1]*

The *"October median"* is the greatest median value among the 12 months. The *"monthly median/October median"* component generates a natural proportionality between the median values. The monthly variability concept is shown in the component *(130 cfs-Monthly Median)* as a multiplier with an emphasis placed on the low flow months. This method creates a transition around the breakpoint, which keeps the variability in the system without creating an artificial level of constant flow during certain conditions. The added flow for each month is shown in **Table 8-1**.

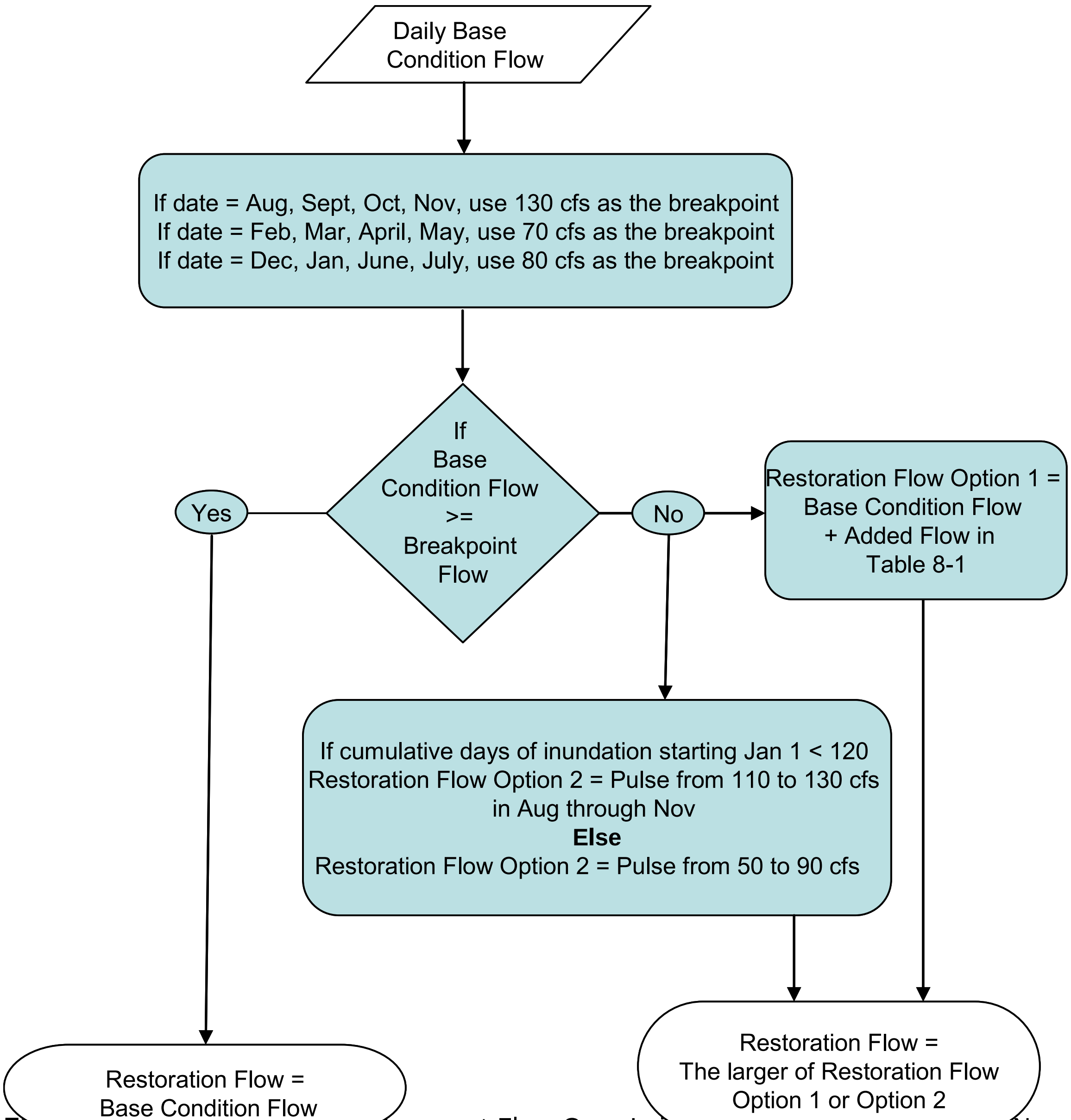


Figure 8-1. Flow Diagram to Augment Flow Over Lainhart Dam to Generate the New Variability Time Series of the Restoration Flow.

Table 8-1. Amount of Additional Flow Needed Over Lainhart Dam Based on Monthly Medians.

Month	Monthly Median (cfs)	Added Flow (cfs)
January	57	37
February	44	34
March	43	34
April	28	25
May	25	24
June	80	36
July	78	36
August	73	37
September	95	29
October	112	18
November	82	35
December	61	38

The second method prescribes a pulse to simulate a hydrograph induced by a rainfall event. There are two magnitudes of pulses. The first one has a mean daily flow of 115 cfs with a range from 110 cfs to 130 cfs. This pulse is applied only in the months of August through November when the 120-day floodplain inundation requirement has not been met in the calendar year. The second pulse has a mean daily flow of 68 cfs, ranging from 50 cfs to 90 cfs. A 90 cfs maximum flow is selected to ensure that water will not flow into the floodplain during the dry season as field verified by our observations described in Chapter 5. This pulse is used throughout the year. The duration of a pulse can be variable. An example of a weekly pulse and biweekly pulse is shown in **Figure 8-2**. The amount of water needed per week for the weekly pulse and the biweekly pulse is about the same.

With the flow augmentation rules described above, a variable flow scenario for Lainhart Dam is generated with a weekly pulsing option. The monthly median flow of the new variable flow scenario is compared with that of the base condition in **Figure 8-3**. Note that the monthly variability is carried over in the new scenario as shown by the different medians between months. Since the total amount of water added over Lainhart Dam in the variable flow scenario is similar to that of the scenario of LD90TB100 evaluated in **Chapter 7**, this Lainhart Dam variable flow scenario is abbreviated as LV90 in this document.

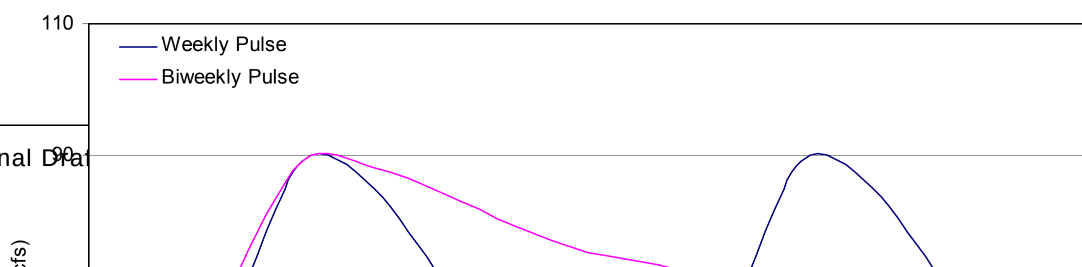


Figure 8-2. A Comparison of a Weekly Pulse and a Biweekly Pulse Used for Flow Augmentation Over Lainhart Dam.

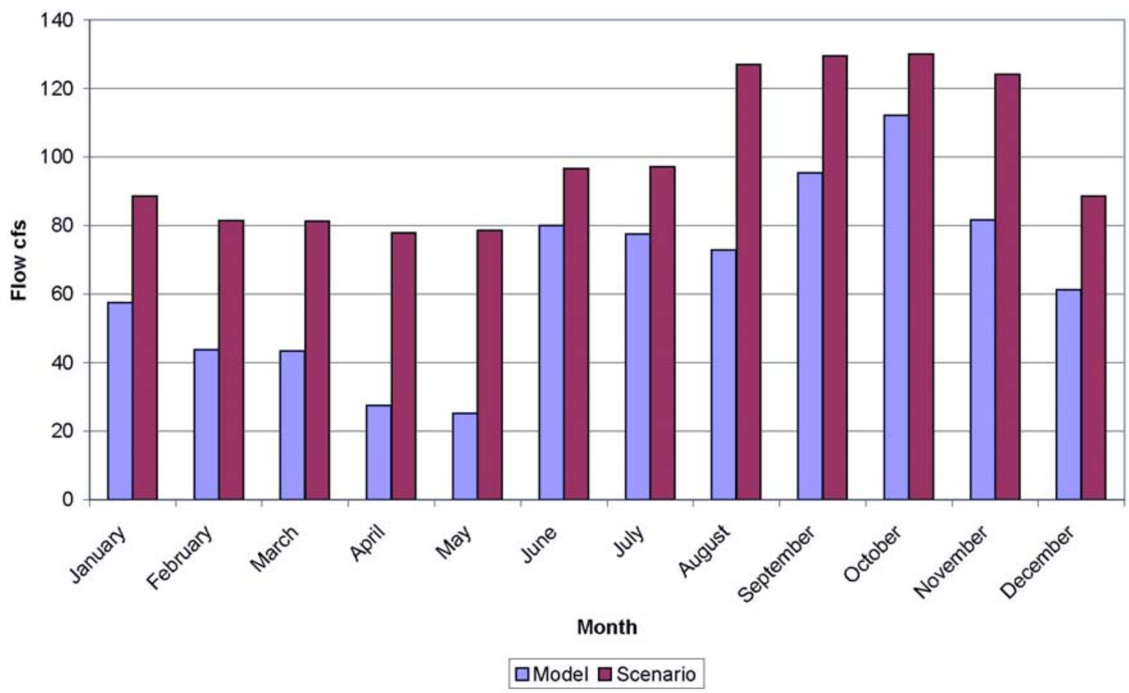


Figure 8-3. Comparison of Lainhart Dam Monthly Median Flow Between the Variable Flow Scenario and the Base Condition.

For the other tributaries, three variable flow scenarios are designed simply to augment the base flow uniformly by 30, 60, and 90 cfs, respectively, if the total Northwest Fork flow with LV90 is less than 300 cfs. Since close to 90% of the daily flow during the 39-year period of record (base condition) is over 30 cfs, the three tributary variable flow scenarios are abbreviated

TV60, TV90, and TV120. An example of how flow is added with the three scenarios is shown in **Figure 8-4.**

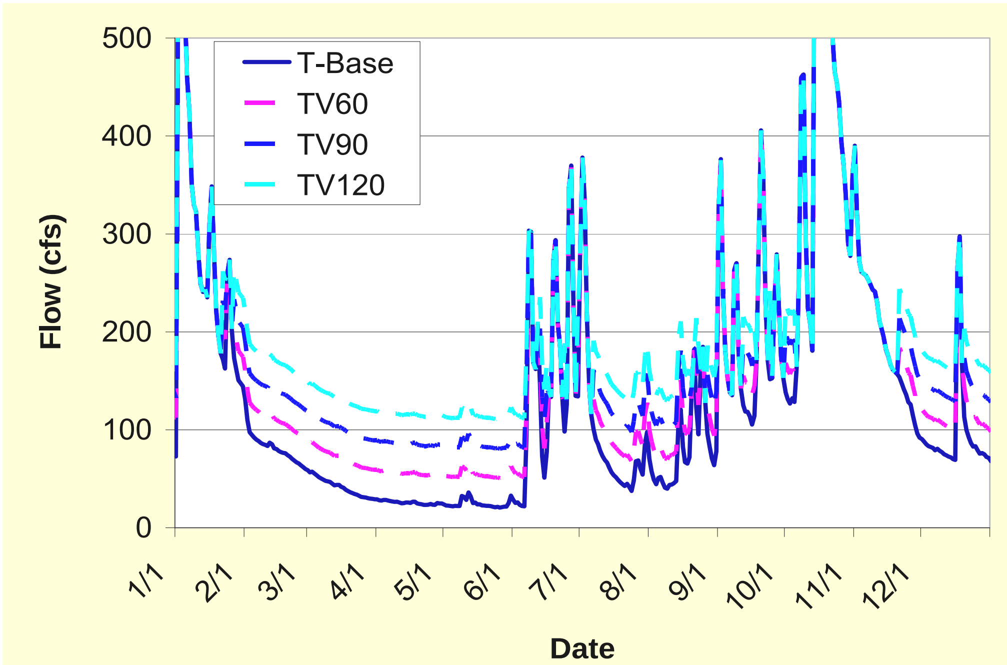


Figure 8-4. Tributary Flow Augmentation for TV60, TV90, and TV120 Compared to Base Condition During a Calendar Year.

After integrating flows of Lainhart Dam (LV90) and the other tributaries, three Northwest Fork variable flow restoration scenarios were formulated: LV90TV60, LV90TV90, and LV90TV120. Daily salinity at the 15 salinity evaluation sites under each of the variable flow scenarios were simulated using the Long-term Salinity Management Model (LSMM) described in **Chapter 6**. Average salinities of the **Base Condition** and the three variable flow scenarios at RM 6, RM 6.5, RM 7, RM 7.5, and RM 8 are summarized in **Figure 8-5.** Daily flow and salinity data were used for VEC evaluations in the next section.

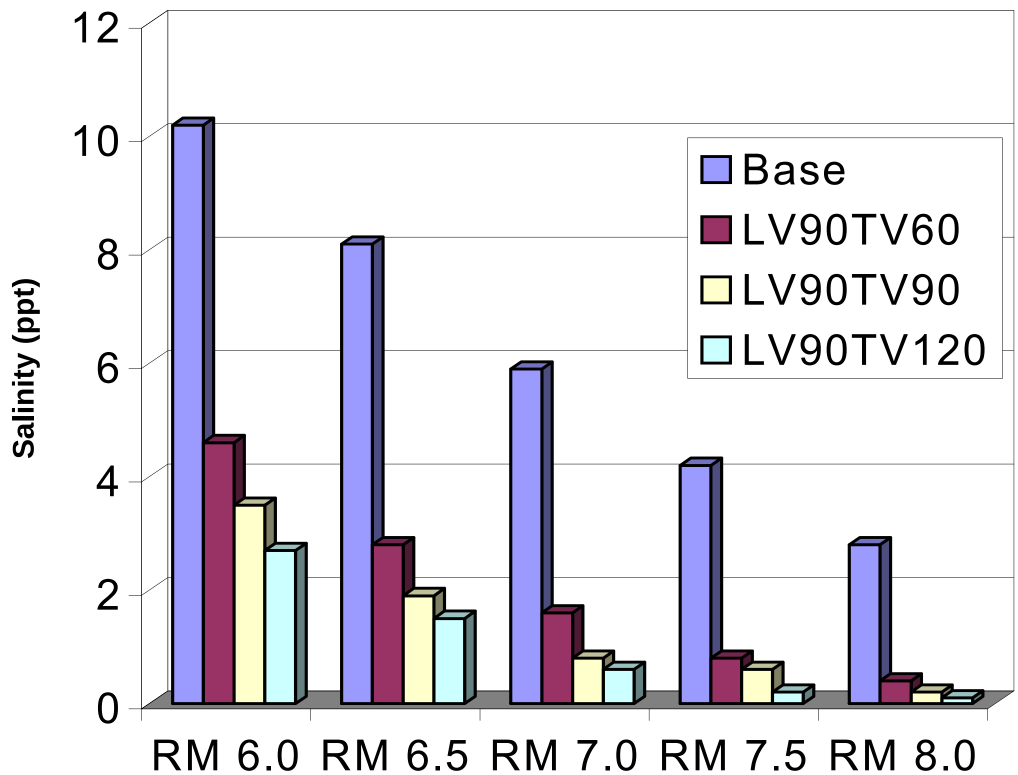


Figure 8-5. Average Salinities of the Base Condition and Three Variable Flow Scenarios at RM 6.0, RM 6.5, RM 7.0, RM 7.5, and RM 8.0.

ECOLOGICAL EVALUTION OF VARIABLE FLOW SCENARIOS

EVALUATION OF RIVERINE FLOODPLAIN

Lainhart Dam flow and river stage relationships were established previously in **Chapter 5** and floodplain inundation characteristics for the riverine reach were illustrated in **Figures 7-2** and **7-3** for Transects 1 and 3, respectively. The floodplain swamp inundation analyses were again conducted using the daily flow of the three variable flow scenarios (**LV90TV60**, **LV90TV90**, and **LV90TV120**). Because most of the tributaries are downstream of the major riverine floodplain, the total flow contribution from the other tributaries will not likely influence the inundation levels in the riverine reach. Thus, only the **LV90** component of the variable flow was evaluated.

Since **LV90** was designed to meet the hydroperiod requirements of the riverine swamp, it is anticipated that the performance measures of the riverine floodplain will be fully met by **LV90**. **Table 8-2** is the monthly mean flow of **LV90.** With the **LV90** scenario, dry season mean monthly flows were all greater than 65 cfs. The number of months with a mean flow greater than 90 cfs in **LV90** is also less than that of **LD90TB110**. It shows that **LV90** has a much improved mean monthly flow regime than the **Base Condition** (**Chapter 7, Table 7-4**) and the constant flow scenario, **LD90TB110** (**Chapter 7, Table 7-6**).

Table 8-2. Examination of Flow Conditions of the LV90 Restoration Scenario for the 39-Year Modeled Dataset Using Mean Monthly Flows (cfs).

Dry Season	Wet Season
< 35	< 35
>= 35 & < 65	>= 35 & < 65
>= 65 & <=90	>= 65
> 90	

	Date												
Years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Mean
1965	75	77	69	70	69	73	79	124	120	188	131	69	96
1966	114	116	73	71	95	213	221	160	127	208	98	77	131
1967	71	82	79	71	69	92	114	152	126	207	114	72	104
1968	69	71	69	70	75	303	180	161	220	274	163	99	146
1969	101	81	133	71	158	126	106	163	164	271	186	100	139
1970	131	107	216	237	110	159	122	108	89	89	72	70	126
1971	69	74	69	70	93	75	81	123	165	133	209	105	106
1972	82	77	71	78	195	204	105	123	120	76	103	73	109
1973	76	74	70	70	70	109	104	149	155	188	91	82	103
1974	171	74	84	70	70	145	152	173	121	145	94	94	117
1975	71	79	70	70	76	121	146	119	144	144	75	69	99
1976	69	80	71	70	138	128	72	134	196	125	102	72	105
1977	98	72	69	70	83	74	69	120	272	121	113	151	109
1978	104	73	71	70	70	166	147	173	128	177	267	190	137
1979	193	91	85	87	82	90	74	118	189	170	140	97	118
1980	85	89	74	70	84	78	111	120	121	139	93	70	95
1981	69	71	69	70	69	70	69	205	184	120	125	73	100
1982	69	72	168	201	175	241	124	127	135	156	303	182	163
1983	143	200	172	108	85	144	106	161	274	342	206	157	175
1984	123	86	127	87	119	133	100	120	215	131	219	155	135
1985	107	77	73	94	70	78	97	120	188	138	96	102	103
1986	145	78	131	100	69	123	125	124	127	121	121	126	116
1987	126	73	96	71	70	77	86	121	123	177	242	74	111
1988	89	80	81	70	77	111	138	215	128	117	70	69	104
1989	69	71	69	70	69	70	73	135	120	137	120	74	90
1990	70	71	69	70	71	73	69	131	154	174	120	76	96
1991	168	132	81	142	132	162	135	130	149	198	124	102	138
1992	86	128	88	80	69	155	137	206	220	173	208	100	137
1993	231	204	200	122	92	110	99	118	174	281	167	98	158
1994	102	142	84	97	84	147	127	225	281	212	287	285	172
1995	140	96	98	85	84	125	134	292	196	356	271	153	170
1996	103	80	160	122	144	140	176	131	149	171	152	109	137
1997	107	105	84	130	98	214	109	205	227	120	118	149	139
1998	148	204	161	88	115	84	105	121	227	143	293	102	149
1999	227	89	84	71	69	182	134	143	203	337	213	109	155
2000	107	84	90	110	70	71	77	118	128	199	78	71	100
2001	69	71	92	72	70	93	206	265	265	236	166	106	143
2002	104	132	83	78	69	139	189	121	120	90	87	78	107
2003	70	71	96	78	146	141	82	165	129	121	170	103	114
Monthly Mean	109	96	98	90	94	129	117	152	169	177	154	106	124

Table 8-3 is a summary of the number of days with a 20-day moving average flow over 110 cfs. The months which have flow larger than 110 cfs for over 20 days are highlighted green. Note that the highlighted months occur mostly in the wet season from July to November when the floodplain needs to be inundated. Compared with the **Base Condition** (**Chapter 7, Table 7-8**) and **LD90TB110** (**Chapter 7, Table 7-10**), LV90 is an improvement over the constant flow scenario the in terms of meeting the requirement of floodplain inundation.

Table 8-3. Floodplain Swamp Inundation Analysis for **LV90**: Number of Days in a Month with 20-Day Moving Average Flows Greater than 110 cfs.

	Date													Months with
Years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Grand Total	over 20 days
1965	0	0	0	0	0	0	0	20	30	31	28	0	109	4
1966	18	5	16	0	0	26	31	31	30	31	16	0	204	5
1967	0	0	0	0	0	0	22	23	30	31	24	0	130	5
1968	0	0	0	0	0	26	31	31	30	31	30	14	193	6
1969	0	0	22	0	25	27	21	20	30	31	30	15	221	8
1970	18	23	21	30	14	30	23	15	0	1	0	0	175	5
1971	0	0	0	0	2	0	0	21	30	31	30	12	126	4
1972	12	0	0	0	19	30	17	28	30	8	2	4	150	3
1973	0	0	0	0	0	14	2	31	30	31	17	0	125	3
1974	17	9	0	0	0	15	31	31	30	31	0	4	168	4
1975	0	0	0	0	0	15	26	31	30	31	11	0	144	4
1976	0	0	0	0	8	26	0	14	30	31	22	0	131	4
1977	0	0	0	0	0	0	0	14	30	31	27	20	122	4
1978	14	9	0	0	0	10	31	31	30	31	30	31	217	6
1979	31	13	0	0	0	0	0	15	30	31	27	15	162	4
1980	0	0	0	0	0	0	4	31	30	31	19	0	115	3
1981	0	0	0	0	0	0	0	15	30	31	30	5	111	3
1982	0	0	23	30	29	30	26	24	11	31	30	31	265	9
1983	31	28	31	28	1	22	2	24	30	31	30	31	289	10
1984	23	0	8	14	2	25	0	22	30	29	16	29	198	6
1985	5	0	0	0	0	0	0	26	30	31	18	9	119	3
1986	22	1	4	21	0	10	23	31	30	22	30	15	209	7
1987	24	0	0	0	0	0	0	18	30	31	30	12	145	4
1988	0	0	0	0	0	17	17	31	30	31	1	0	127	3
1989	0	0	0	0	0	0	0	19	30	31	30	6	116	3
1990	0	0	0	0	0	0	0	15	30	31	30	6	112	3
1991	15	24	0	21	19	30	31	31	30	31	28	13	273	8
1992	0	8	15	0	0	5	27	26	30	31	30	18	190	5
1993	27	28	31	25	0	6	0	17	30	31	30	16	241	7
1994	0	26	10	0	0	21	26	31	30	31	30	31	236	8
1995	31	5	0	0	0	6	28	31	30	31	30	31	223	7
1996	3	3	20	23	9	30	31	30	30	31	30	21	261	9
1997	0	6	7	15	6	29	28	29	30	30	30	31	241	7
1998	15	28	31	10	20	0	12	24	30	31	30	17	248	7
1999	29	13	0	0	0	18	25	25	30	31	30	25	226	7
2000	14	0	0	15	4	0	0	15	30	31	8	0	117	2
2001	0	0	0	0	0	0	30	31	30	31	30	12	164	5
2002	0	18	5	0	0	10	31	31	30	8	0	0	133	3
2003	0	0	0	0	6	30	2	23	30	31	30	6	158	5
Grand Total	349	247	244	232	164	508	578	956	1,121	1,121	894	480	6,894	203

EVALUATION OF TIDAL FLOODPLAIN

Figure 8-6 shows the distribution of average daily salinity at RM 7, RM 7.5, and RM 8 during the 39-year simulation period of the variable flow scenarios. For the **LV90TV60,** 95% of the daily salinities were below 1 ppt and 100% were below 2 ppt at RM 8. This is encouraging for restoration of freshwater floodplain communities particularly above RM 8 and includes Kitching Creek, one of the major tributaries in need of protection and restoration in the upper tidal reach.

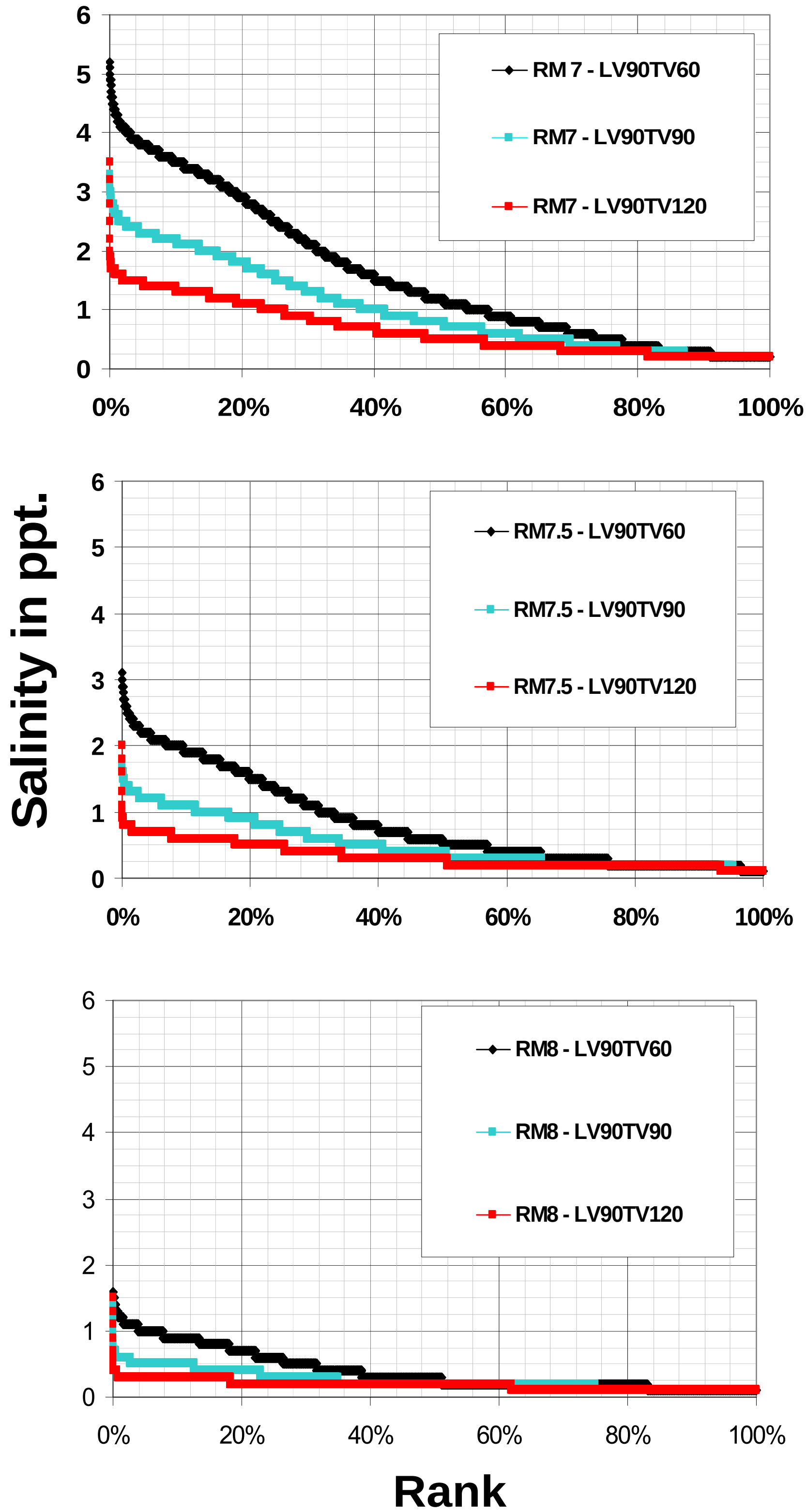


Figure 8-6. A Ranking of Average Daily Salinity by Variable Flow Scenario at RM 7 (1/2 mile upstream of Transect 9), RM 7.5 and RM 8 (adjacent to and downstream of the mouth of Kitching Creek).

In examining the salinity distribution of the variable flow scenarios, one can easily obtain the characteristic salinity regime as defined by the *Ds/Db* ratio (**Chapters 4** and **7**). **Figure 8-7** depicts the approximate location of the characteristics salinity regime with a *Ds/Db* ratio smaller than 0.5 (using 1 ppt or 2 ppt as the threshold) for healthy growth of bald cypress and cabbage palm produced by **LV90TV60**, **LV90TV90**, and **LV90TV120**. Note that the characteristic salinity regime using 1 ppt threshold will be roughly at RM 7.5 for **LV90TV60**. Additional flow augmentation with **LV90TV90** and **LV90TV120** resulted in moving the location further downstream. However, the floodplain area from RM 7.5 to RM 6.8 consists of primarily peninsulas and islands, which receive tidal waters from multiple areas of the river channel. Due to the meandering nature of this particular section of the river, the improvement in freshwater environment of **LV90TV90** and **LV90TV120** does not seem to be practical for restoration purposes.

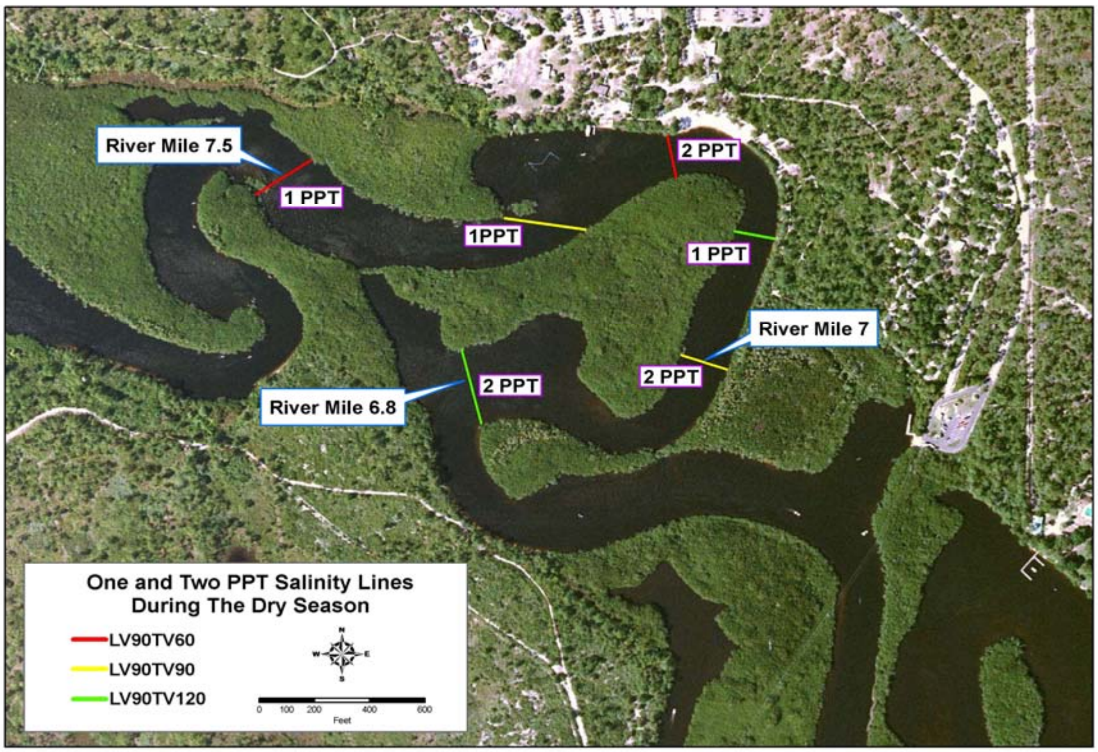
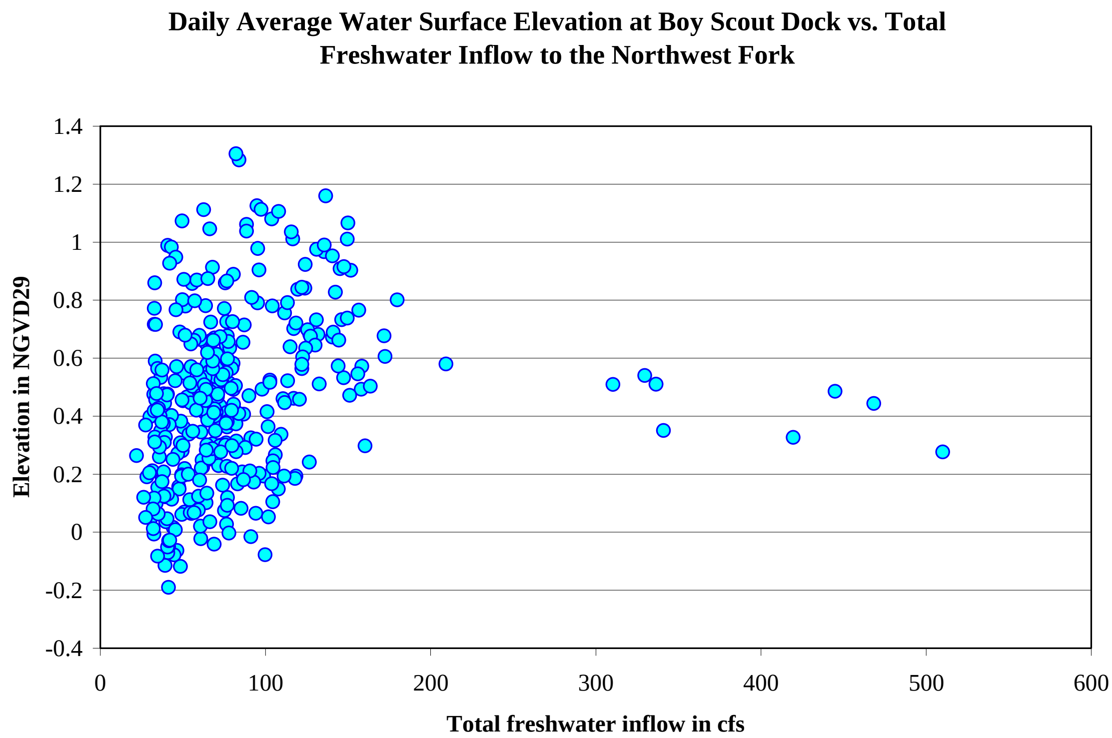


Figure 8-7. Approximate Locations of Characteristic 1 ppt and 2 ppt Salinity Lines Under Variable Flow Scenarios LV90TV60, LV90TV90 and LV90TB120.

The impact of increased dry season flows on floodplain swamp inundation is minimal. The measured daily average water surface elevations at the Boy Scout Dock (RM 5.92) and Kitching Creek (RM 8.13) stations were plotted against total Northwest Fork flow in **Figure 8-8.** The river stages at both locations are highly variable due to tidal influences; there is no clear relationship between the flow and stage in the tidal reaches of the Northwest Fork.



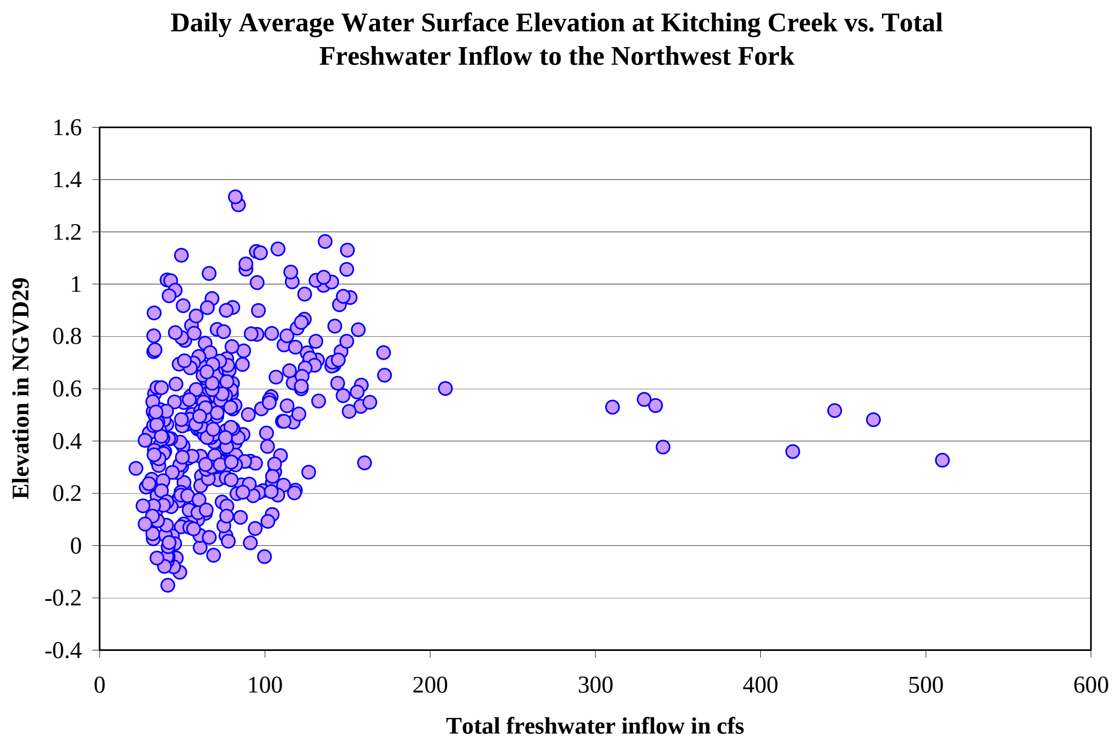


Figure 8-8. Water Surface Elevations at Varying Total Freshwater Flows at Two Tidal Floodplain Locations During the Dry Season.

Figures 8-9 and **8-10** provide a another illustration of the frequencies of floodplain inundation during a dry season (April 2004) and a wet season (November 2004) at Kitching Creek (RM 8.13), which is near Transect 6 at RM 8.43, and Boy Scout Dock (RM 5.92), which is approximately ½ mile away from Transect 9 at RM 6.46 in the lower tidal reach. Although the tidal amplitude was nearly the same at these two locations, the floodplain elevations are not the same. The average elevation of floodplain swamp plots at Transect 6 is 1.71 ft whereas the average elevation at Transect 9 is 1.57 ft and has more days of floodplain inundation than Transect 6. **Figure 8-11** shows the surveyed elevation of Transect 9. There is a marked change in vegetation type from the mangrove floodplain forest (LTsw1 and LTsw2) to hydric hammock (HH) to upland forest vegetation. The three remaining live bald cypress trees on Transect 9 are located near the trail (elevation about 2 feet), and the cabbage palms of the LTMix (Lower Tidal Mix) are also elevated about 2 feet. Because of their slightly higher elevation (6 inches above the floodplain), the cypress trees and cabbage palms are protected from most tidal effects. The elevations of adjacent islands and peninsulas between RM 7.5 and RM 6.8 (**Figure 8-7**) are expected to be lower than the floodplain elevation of Transect 9. Thus, the low elevations of the floodplains and riverbeds compound the problems associated with tidal amplitude and floodplain inundation and limit the potential for restoring freshwater vegetation in this segment of the lower tidal reach.

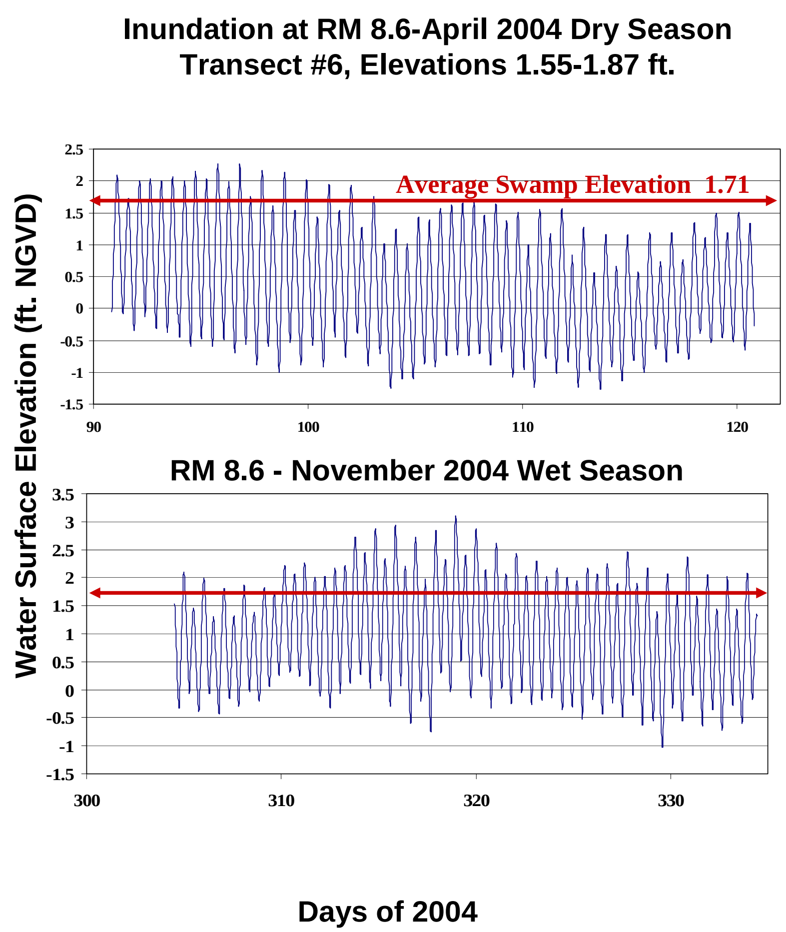


Figure 8-9. Tidal Amplitude at Kitching Creek (RM 8.13) During April (Wet Season) and November (Dry Season) of 2004 Relative to Transect 6 (RM 8.43) Elevation.

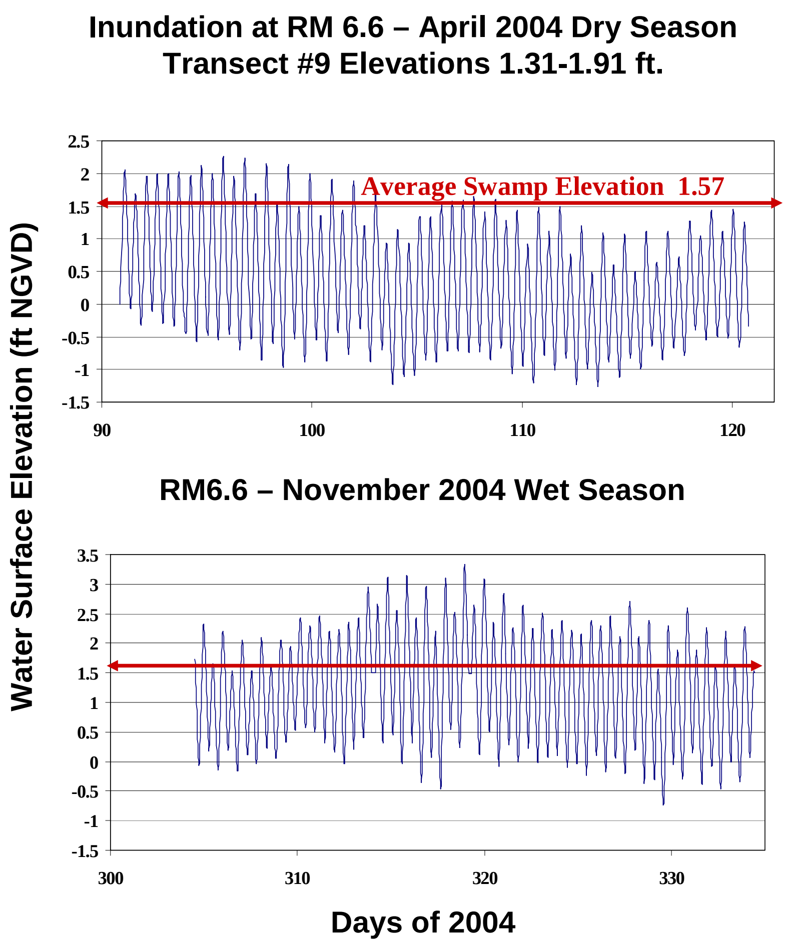


Figure 8-10. Tidal Amplitude at Boy Scout Dock (RM 5.92) During April (Wet Season) and November (Dry Season) of 2004 Relative to Transect 9 (RM 6.46) Elevation.

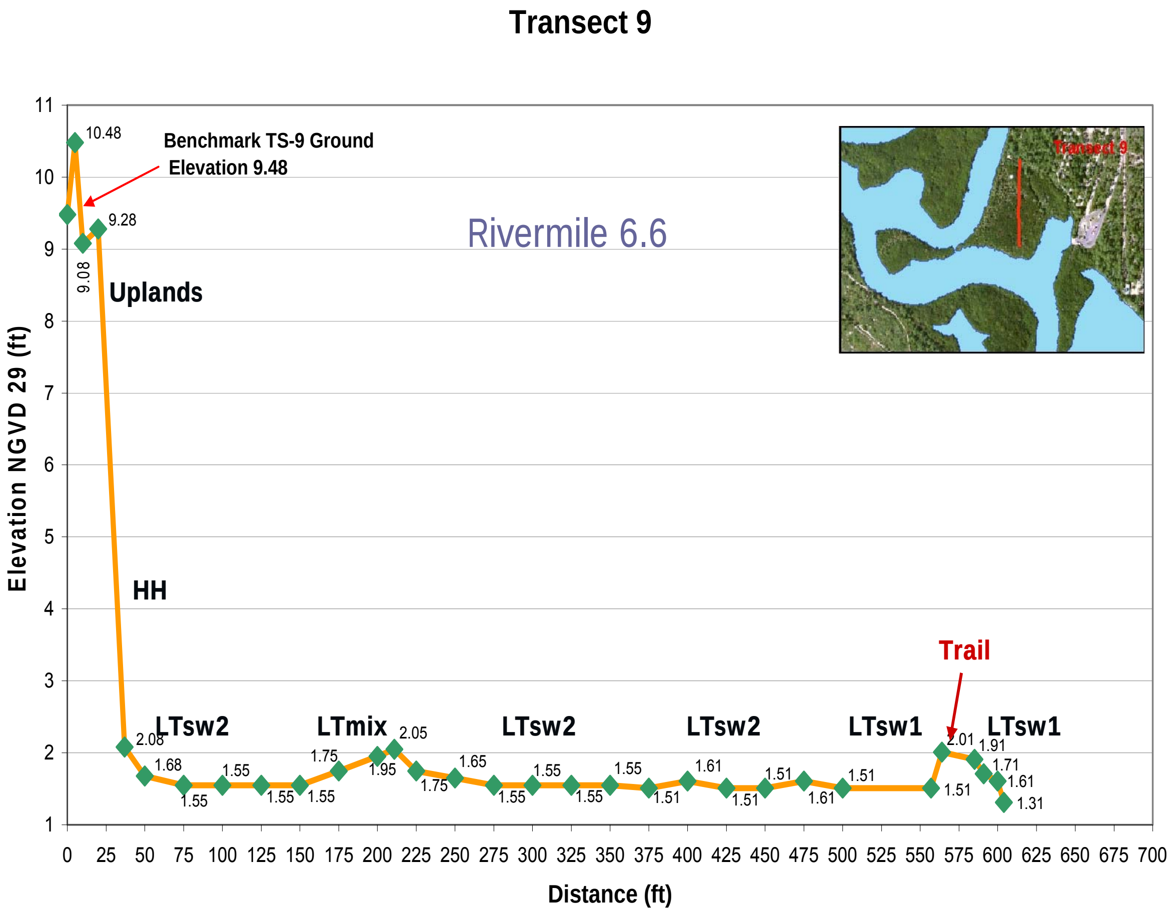


Figure 8-11. Vegetation Types and Elevations Along Transect 9, RM 6.46.

Upon examination of the proceeding salinity, tidal amplitude, and topographical data, it was concluded that **LV90TV60** (flows over Lainhart Dam and from the downstream tributaries) was the preferred restoration scenario for the riverine and tidal floodplains of the Northwest Fork of the Loxahatchee River. The additional flows provided by the **LV90TV90** and **LV90TV120** scenarios would have very little impact on the restoration and enhancement of freshwater vegetation in the lower tidal reaches because of the low floodplain elevations and the dominant island/peninsular features.

EVALUATION OF ESTUARINE BIOTA

Low Salinity Zone Evaluation: Variable Flow scenarios for Fish Larvae

The evaluation of fish larvae distribution and abundance in relation to salinity and flow in the Northwest Fork in **Chapter 7** established the preferred salinity range for fish larvae of 2 to 8 ppt would seldom move downstream of RM 5.5 during the dry season (from February to June) when fish larvae are most abundant. However, a more natural variable flow and salinity gradient in the LSZ can enhance environmental conditions for fish larvae. Additional salinity analysis was needed for variable flows because the previous results were based on the effect of constant flows on the salinity gradient (**Figure 7-11**). As managed or naturally variable flows increase and decrease, salinity isohalines move downstream and upstream affecting fish larvae abundance and distribution. Therefore, to evaluate the comparative affects of variable flow scenarios on fish larvae, it is determined the frequency and duration of the events in which the salinity is less than the minimum desired high salinity threshold of 8 ppt at the most downstream location is appropriate. RM 5.5 was chosen as the downstream location because it hydrodynamically supports the formation of a turbidity maximum and it has appropriate shoreline habitat for fish larvae settlement. Therefore, this detailed analysis of variable flow alternatives was conducted using modeled salinity data at RM 5.45.

Figure 8-12 shows the frequency expressed as the percent of time of low salinity events (< 8 ppt) with duration ranging from 1 to 25 days at RM 5.45 during February to June for the base condition and the variable flow scenarios during the 39-year period of record. It is apparent that as flow increases, the frequency and duration of the low salinity events also increases. When compared with the base condition, **LV90TV60** results in an increase in exceedences for about 9 - 15%. However, the number of exceedences ranges from 18 - 28% for **LV90TV90** and for from 35 - 50% for **LV90TV120**. Even though the flows from the tributaries increase by an increment of 30 cfs, the frequency and duration of salinity threshold exceedences increases rapidly when compared with the base case. This increase in salinity threshold exceedences shows the sensitivity of the system to small increases in flows once mean base flow of 170 cfs is reached. The impact of these increased numbers of exceedences on the function of the low salinity zone for fish larvae survival is difficult to quantify. The lowest flow alternative (**LV90TV60**) is recommended because of the relatively small increase in exceedences. Additional information is needed to evaluate the affects of flows on fish larvae productivity. A study has been proposed in the “Special Studies” section of **Chapter 10** to determine the relationship among varying base flows, salinity, water quality, turbidity maximum formation, and zooplankton distribution and abundance as part of the adaptive management process.

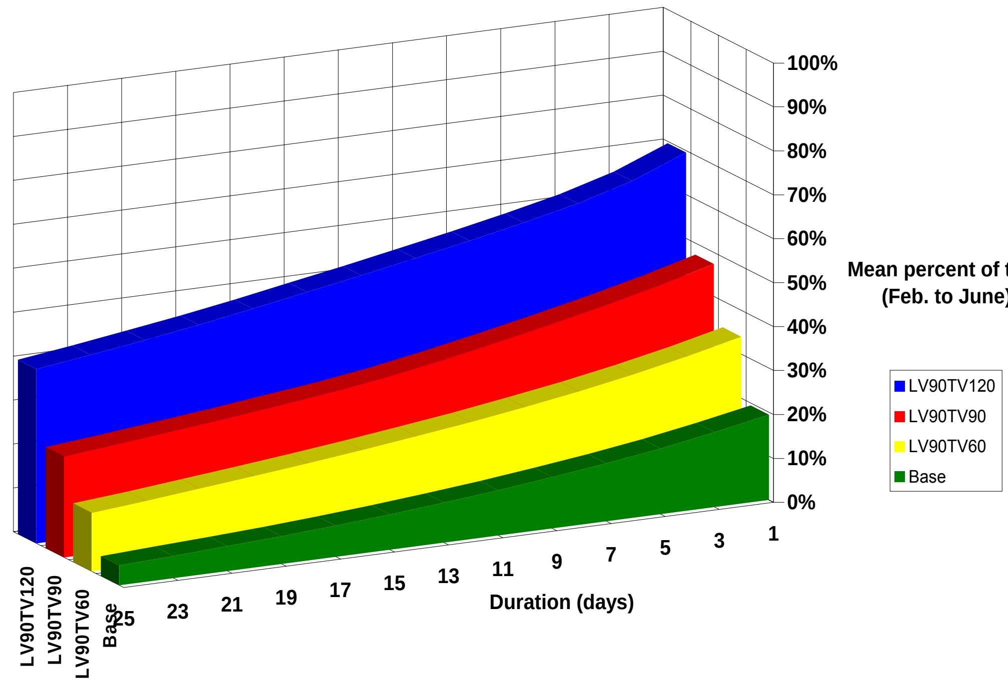


Figure 8-12. Percent Time and Duration When Salinity Was Below 8 ppt at RM 5.45 for Base (1965-2003) and Variable Flow Scenarios.

Mesohaline Zone Evaluation: Variable Flow Scenarios for Oysters

In association with constant flow from Lainhart Dam and downstream tributaries, the evaluation of oysters in the mesohaline zone (**Chapter 7**) revealed levels of oyster stress throughout the Northwest Fork salinity gradient. A critical flow that did not cause significant oyster stress was established from RM 6 to RM 4 where the greatest abundance of oysters occur. These critical flows were about 90 cfs, 130 cfs, 160 cfs, and 230 cfs, at RM 5.92, RM 5.45, RM 4.93, and RM 4.13, respectively (**Table 7-15**). In the evaluation, the distribution and density of the existing oyster population de to be understood to avoid any major impacts to this important resource. To address this issue, **Figure 8-13** was compiled using recent field and GIS data to demonstrate cumulative number and acres of oysters from RM 6 to RM 4. Downstream of RM 6, a small increase in area (~1.75 acres) and number (~ 3 million oysters) of oysters appears near RM 5.5 and remains relatively constant until about RM 5. Beginning at RM 5 a significant increase in oysters occurs from about 2.2 to 10.0 acres and from near 5.8 to 23 million oysters at RM 4. Therefore, approximately 75% of oysters are downstream of RM 5. Utilizing the critical flows established above, an increase in flow to 160 cfs could be managed before significant oyster stress occurs at RM 4.93. Since the majority of oyster resources are downstream of RM 5, a maximum of about 160 cfs total flow (flow from Lainhart Dam and the downstream tributaries) was preferred.

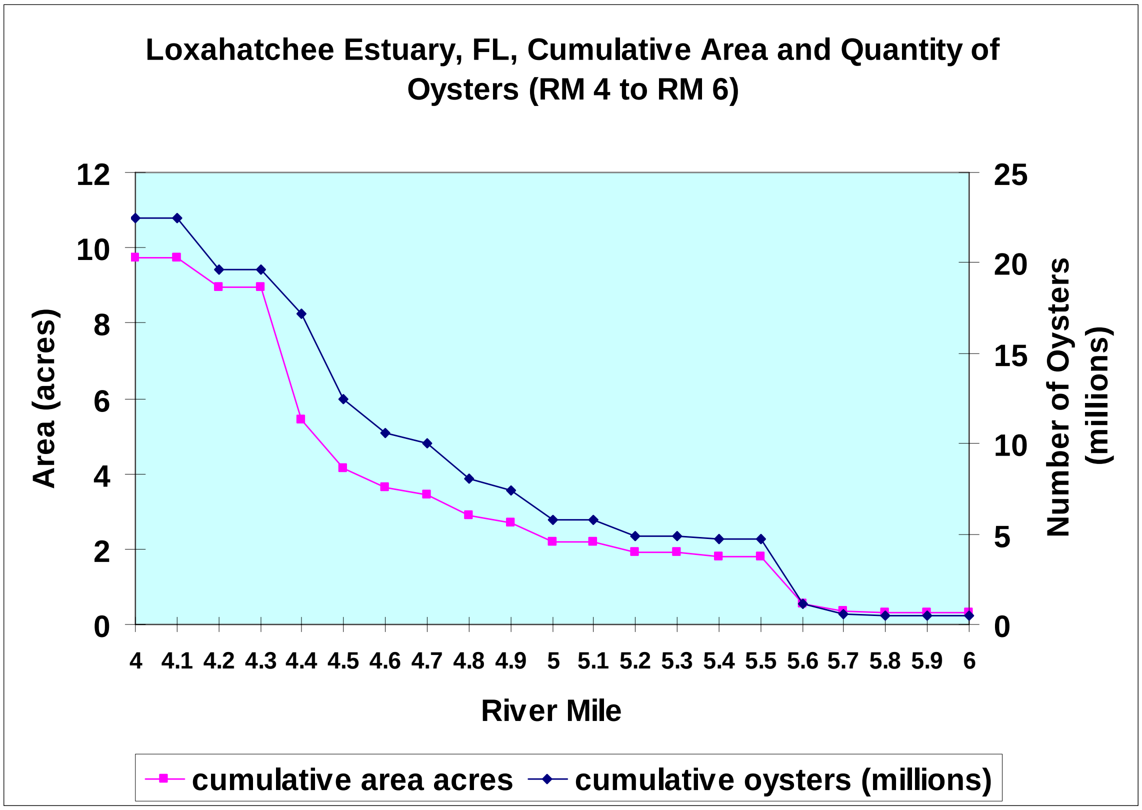


Figure 8-13. Cumulative Number of Oysters and Acreage between RM 4.0 and RM 6.0.

The ecologically preferred method of managing flows is to use variable flows that mimic natural flows. The same methods used to evaluate earlier constant flow scenarios (**Chapter 7**) were used to evaluate these three variable flow alternatives. **Figures 7-16** to **7-23** reveal levels of oyster stress for egg development, larvae, spat, and adults with the constant flow scenarios. The three variable flow alternatives (**LV90TV60**, **LV90TV90**, **LV90TV120**) were evaluated to determine oyster stress levels. The goal is to cause no significant stress on oysters downstream of about RM 5. The **LV90TV60** variable flow scenario, with a total average inflow of about 150 cfs during the dry season, was consistent with the previous preference of 160 cfs.

Figures 8-14 and **8-15** illustrate the stress levels for oyster life stages along the salinity gradient for the base case and the preferred alternative (**LV90TV60**). **Figure 8-14** shows a slight increase in harmful salinity conditions to egg development at Station 5 (RM 4.93) compared to the base case. However, the level of harm is similar to Station 6 (RM 5.45) base case. Salinity conditions causing egg mortality (**Figure 8-14**) in the base case and **TV60** are similar at RM 4.93 and do not exceed egg mortality of the base case at RM 5.45. Harmful salinity conditions for oyster larvae, a sensitive indicator, increased slightly at RM 4.93 to levels found in the base case at RM 5.54 (**Figure 8-14**), however most importantly, larvae mortality was nearly the same as the base case at RM 4.93 (**Figure 8-14**). Oyster spat at RM 4.93 will experience a small increase in harmful salinity (**Figure 8-15**) from a median percentage of time of about 20% for the base case to 30% with alternative **TV60**. This increase in the median to 30%, nevertheless, is similar to what is presently experienced at RM 5.45. **Figure 8-15** indicates that salinity conditions resulting in mortality to year class oyster spat rarely occur during the base case and the preferred alternative. **Figure 8-15** reveals that the median percent of time adults are exposed to harmful salinity conditions increases from about 27% to 48% for the base case to alternative **LV90TV60** at RM 4.93. This 48% of time adults could experience harmful salinity is presently experienced at RM 5.92. However, adult oyster mortality rarely occurred in the base case and under the **LV90TV60** alternative at RM 4.93 (Station 5). Therefore, the salinity environment resulting from the variable flow scenario **LV90TV60** will slightly increase oyster stress near RM 5 but will not increase oyster mortality near RM 5, meeting our goal of maintaining the majority of oysters.

Since oysters migrated upstream in the Northwest Fork under existing dry season flow conditions, it was expected that increased flows would result in greater stress to upstream oyster communities. Increased flows would move favorable salinity conditions downstream where additional substrate (cultch) could be placed to mitigate loss of oyster beds upstream. Plans to mitigate the loss of about 2.5 acres of oyster beds near RM 4 have been included in the "Special Studies" section of **Chapter 10** in this document.

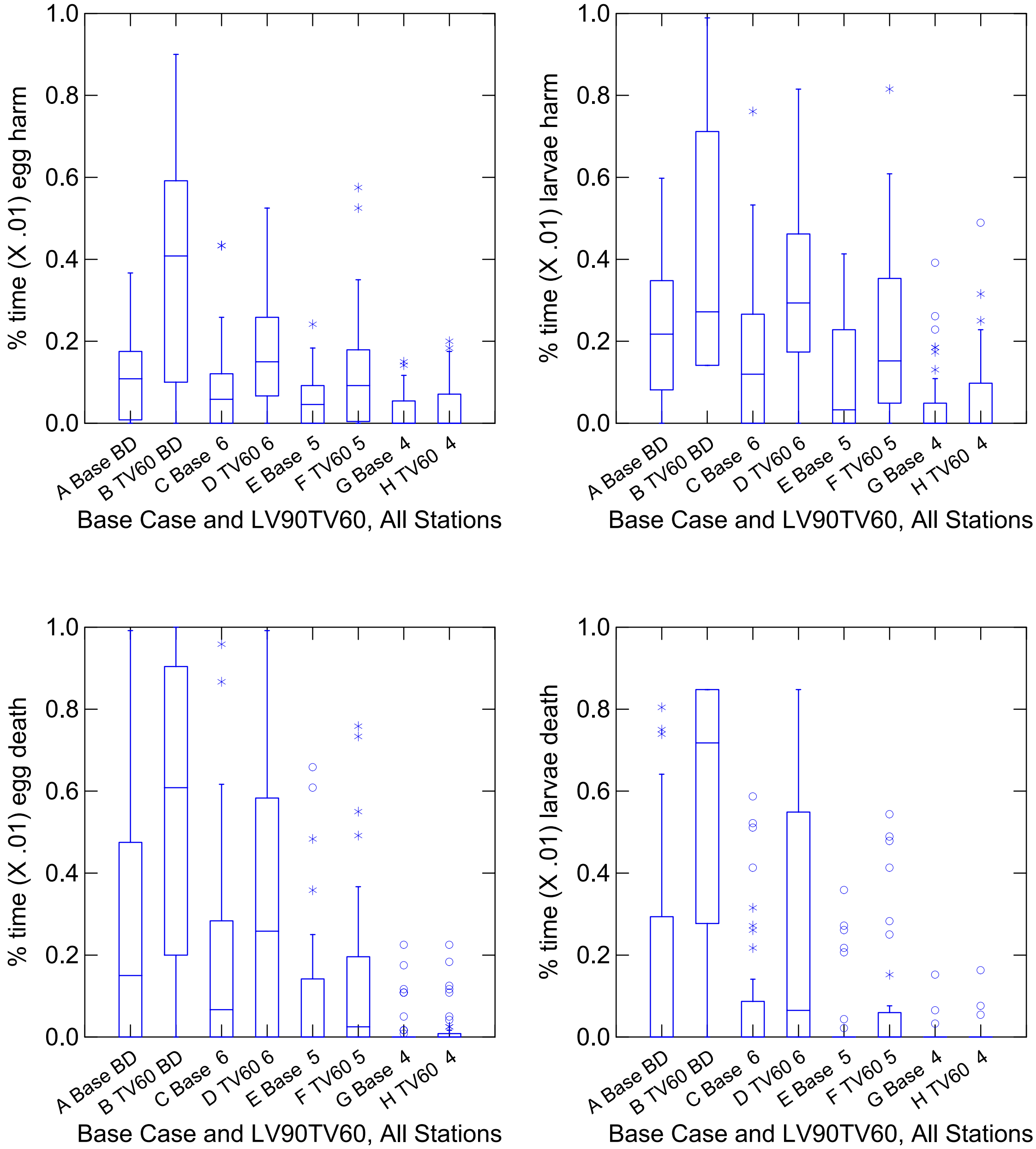


Figure 8-14. Box and Whisker Distribution Plots of the Predicted Percent of Time Harm or Death Conditions Existed for Oyster Eggs and Larvae in the Base Case and LV90TV60 for Oyster Stations BD, 6, 5 and 4.

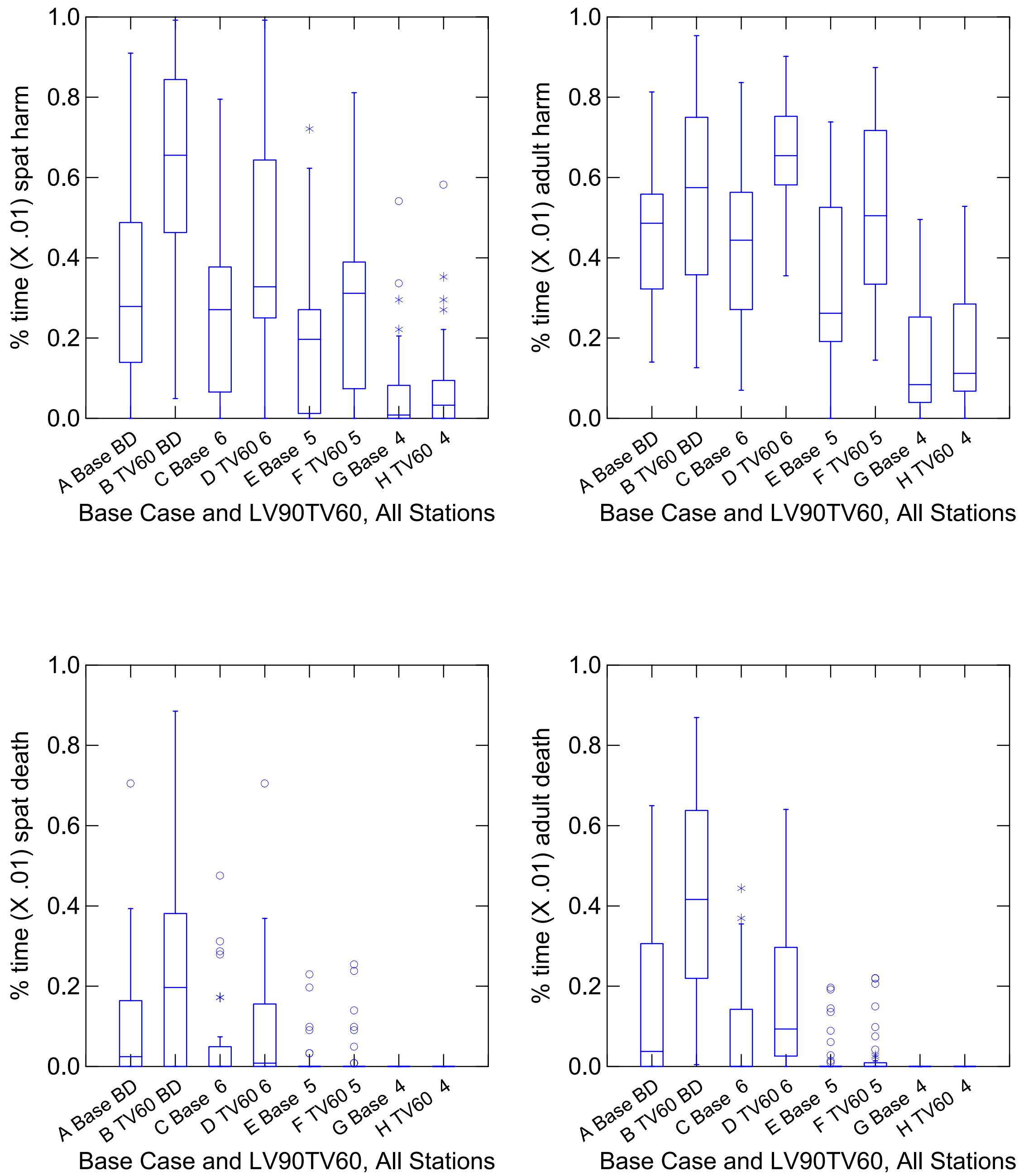


Figure 8-15. Box and Whisker Distribution Plots of the Predicted Percent of Time Harm or Death Conditions Existed for Oyster Spat or Adults in the Base Case and LV90TV60 for Oyster Stations BD, 6, 5 and 4.

Polyhaline Zone Evaluation: Variable flow Scenarios for Seagrasses

Long-Term (39-Year) Data Evaluation

Predicted salinities for nine model runs (6 runs evaluated in **Chapter 7** and 3 variable flow runs) for a 39-year period, were compared to the salinity tolerances of key seagrass species (**Table 4-5**) at five locations along a salinity gradient in the Loxahatchee Estuary. The results for "key" seagrass species are summarized in **Figure 8-16**. Since Johnson's seagrass was found throughout the estuary in 2004, the same evaluation was conducted for this threatened species at all five locations (**Figure 8-17**). Results for the "key species" and Johnson's seagrass evaluations were similar. The three variability salinity runs (**LV90TV60**, **LV90TV90**, and **LV90TV120**) were similar to the base conditions at the four downstream locations where most of the seagrass resources occur. At the most upstream location (**Site 02**) the variability runs began to diverge from base conditions by having fewer "optimal" and more "potential stress" days than the base conditions (these differences were slightly greater for Johnson's seagrass than for the "key" seagrass species). However, the number of "stress" days was similar for base case and variability scenarios.

The 39-year data set was further evaluated at each of the five locations for each variability model run using the performance measures presented in **Table 4-6.** These performance measures are based on literature salinity tolerance values that included **duration** of a salinity threshold associated with a stress event (such as blade mortality). The number of stress events per model run per location are summarized in **Table 8-4**. There were no differences between the number of "stress events" for any of the model runs at any of the sites. Only one stress event was noted and it occurred at **Site 02** for Johnson's seagrass for all model runs in October 1995. This result is consistent with **Figures 8-16** and **8-17** which indicate the number of "stress' days are similar and rare for all model runs.

Short-Term (Wet vs. Dry Year) Data Evaluation

Shorter term data sets were also evaluated. One recent wet year and one recent dry year were selected for this evaluation. The wet year selected was 1995 (the year when all model results showed a "stress event" at **Site 02**) and the recent dry year selected was 2000 (**Figure 8-18**).

For both the wet and dry year, the variability model runs were similar to base conditions at the four downstream locations where most of the seagrass resources occur (**Figure 8-18**). The three variability runs began to diverge from base conditions at the most upstream seagrass location (**Site 02**). However, the number of "stress" days was similar for the base case and variability scenarios in both wet and dry years. Similar results were observed when the wet/dry year evaluation was conducted for Johnson's seagrass (**Figure 8-19**).

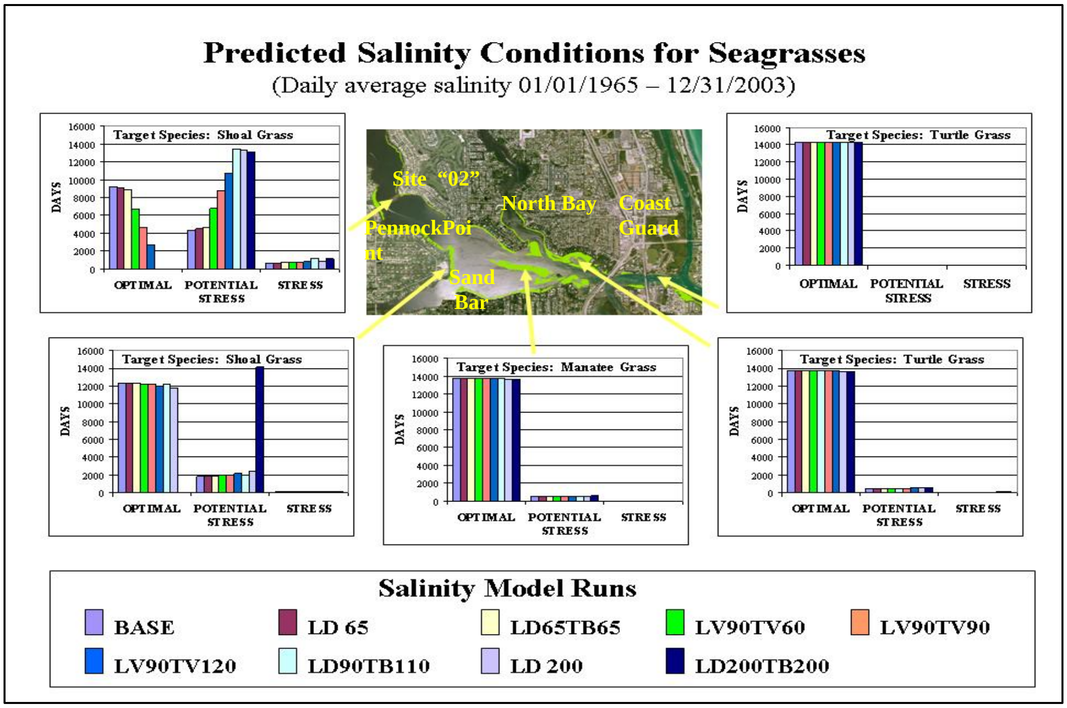


Figure 8-16. Predicted Salinity Conditions for Key Seagrasses at Five Locations Within the Polyhaline Ecozone.

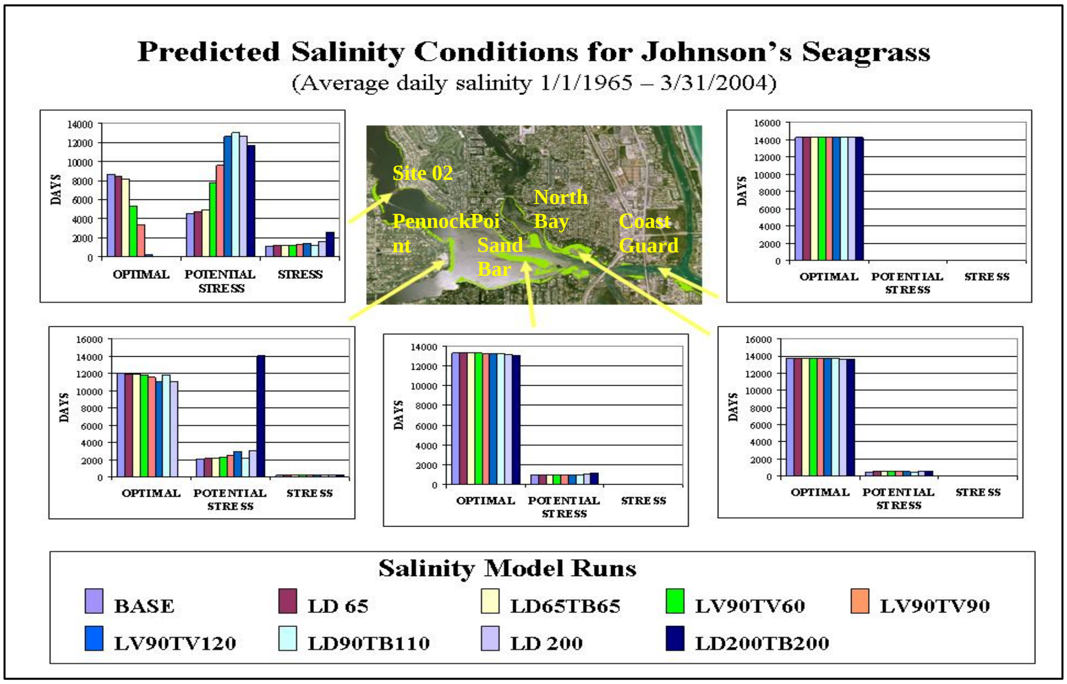


Figure 8-17. Predicted Salinity Conditions for Johnson's Seagrass at Five Locations Within the Polyhaline Ecozone.

Table 8-4. Number of Stress Events per Model Run Based on Daily Average Salinity from 1/1/1965 – 12/30/2003.

Location	Target Seagrass Species	Stress Event (Salinity/Duration Threshold) [a]	Number of Stress Events Per Model Run								
			BASE	LD 65	LD65TB65	LV90TV60	LV90TV90	LV90TV120	LV90TB110	LD 200	LD200TB200
Coast Guard	Turtle grass	≤ 4 ppt for 7 days	0	0	0	0	0	0	0	0	0
	Johnson's seagrass	≤ 5 ppt for 3 days	0	0	0	0	0	0	0	0	0
North Bay	Turtle grass	≤ 4 ppt for 7 days	0	0	0	0	0	0	0	0	0
	Johnson's seagrass	≤ 5 ppt for 3 days	0	0	0	0	0	0	0	0	0
Sand Bar	Manatee grass	≤ 15 ppt for 26 days	0	0	0	0	0	0	0	0	0
	Johnson's seagrass	≤ 5 ppt for 3 days	0	0	0	0	0	0	0	0	0
Pennock Point	Shoal grass	≤ 6 ppt for 30 days	0	0	0	0	0	0	0	0	0
	Shoal grass	≤ 3.5 ppt for 21 days	0	0	0	0	0	0	0	0	0
Site 02	Shoal grass	≤ 6 ppt for 30 days	0	0	0	0	0	0	0	0	0
	Shoal grass	≤ 3.5 ppt for 21 days	0	0	0	0	0	0	0	0	0
	Johnson's seagrass	≤ 5 ppt for 3 days	1	1	1	1	1	1	1	1	1

[a] The duration in this evaluation is in consecutive days.

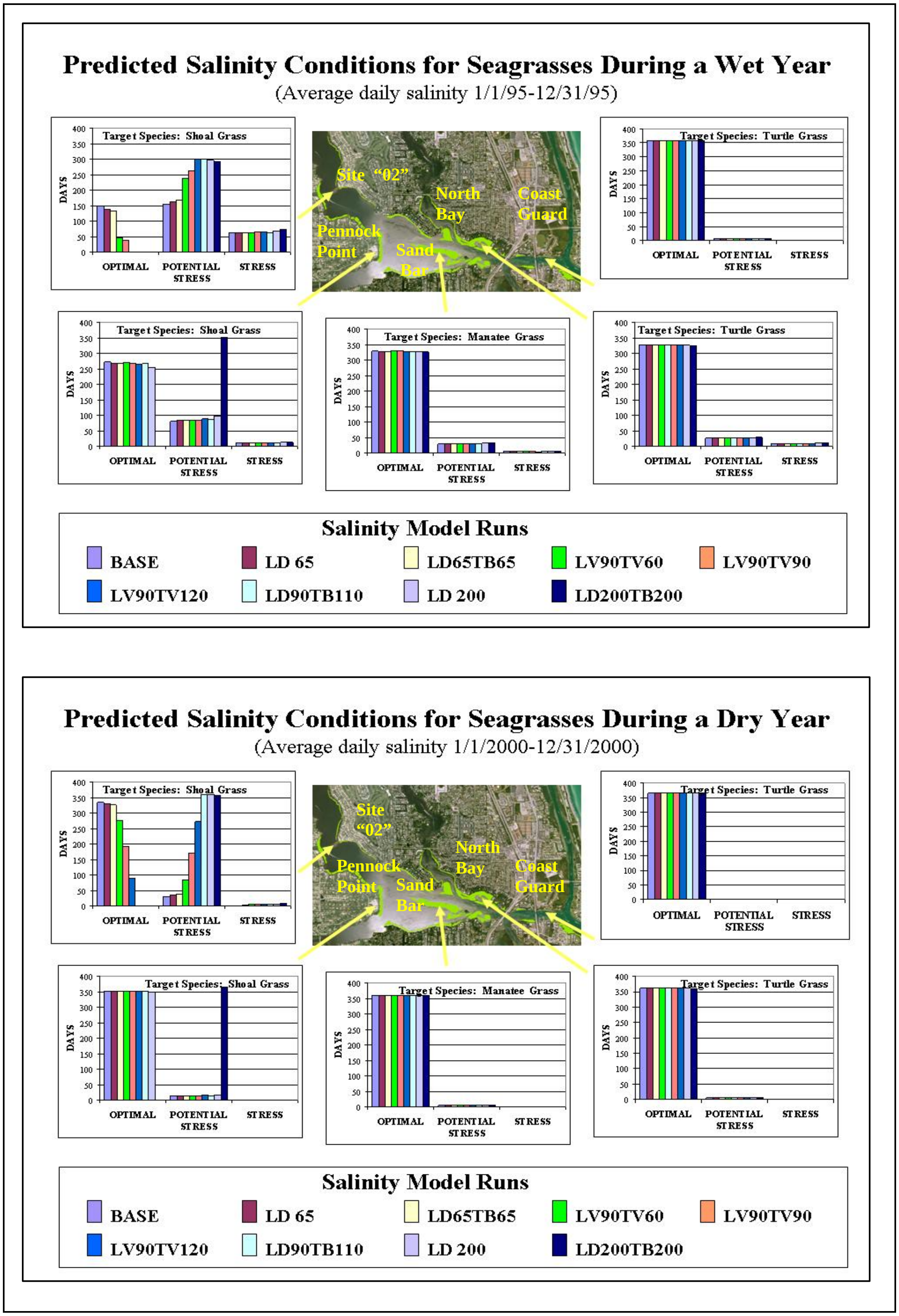


Figure 8-18. Predicted Salinity Conditions for Key Seagrasses at Five Locations Within the Polyhaline Ecozone During a Recent Wet (1995) and Dry Year (2000).

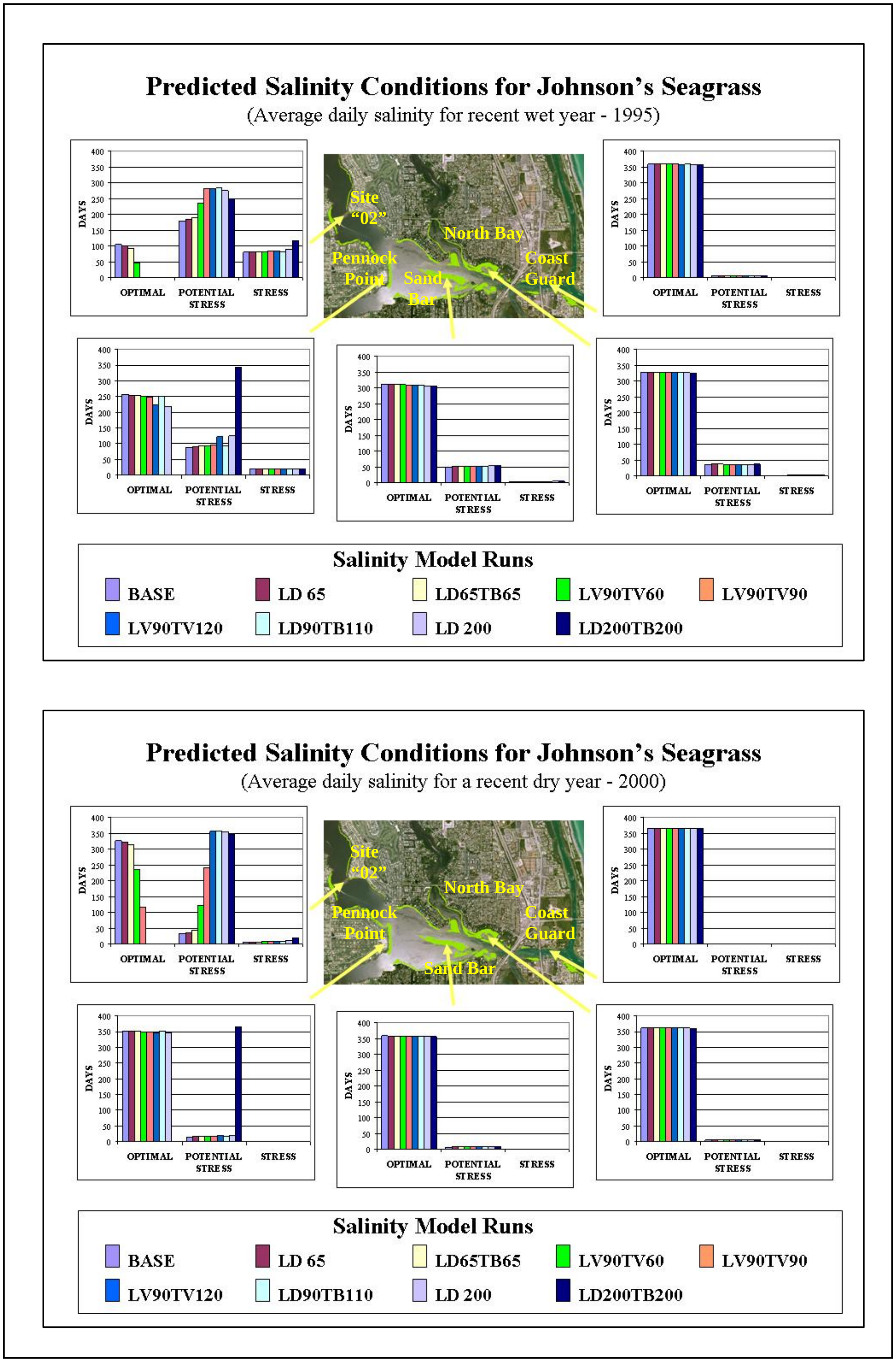


Figure 8-19. Predicted Salinity Conditions for Johnson's Seagrass at Five Locations Within the Polyhaline Ecozone During a Recent Wet (1995) and Dry Year (2000).

In **Chapter 7**, to further evaluate the wet/dry year data, daily average salinities were plotted for three of the seagrass stations (Coast Guard, Sand Bar, and Site 02; **Figure 7-28**). Since no adverse impacts were suggested at the four downstream locations for the variability model runs, only **Site 02** daily average salinities were plotted for this evaluation (**Figure 8-20**).

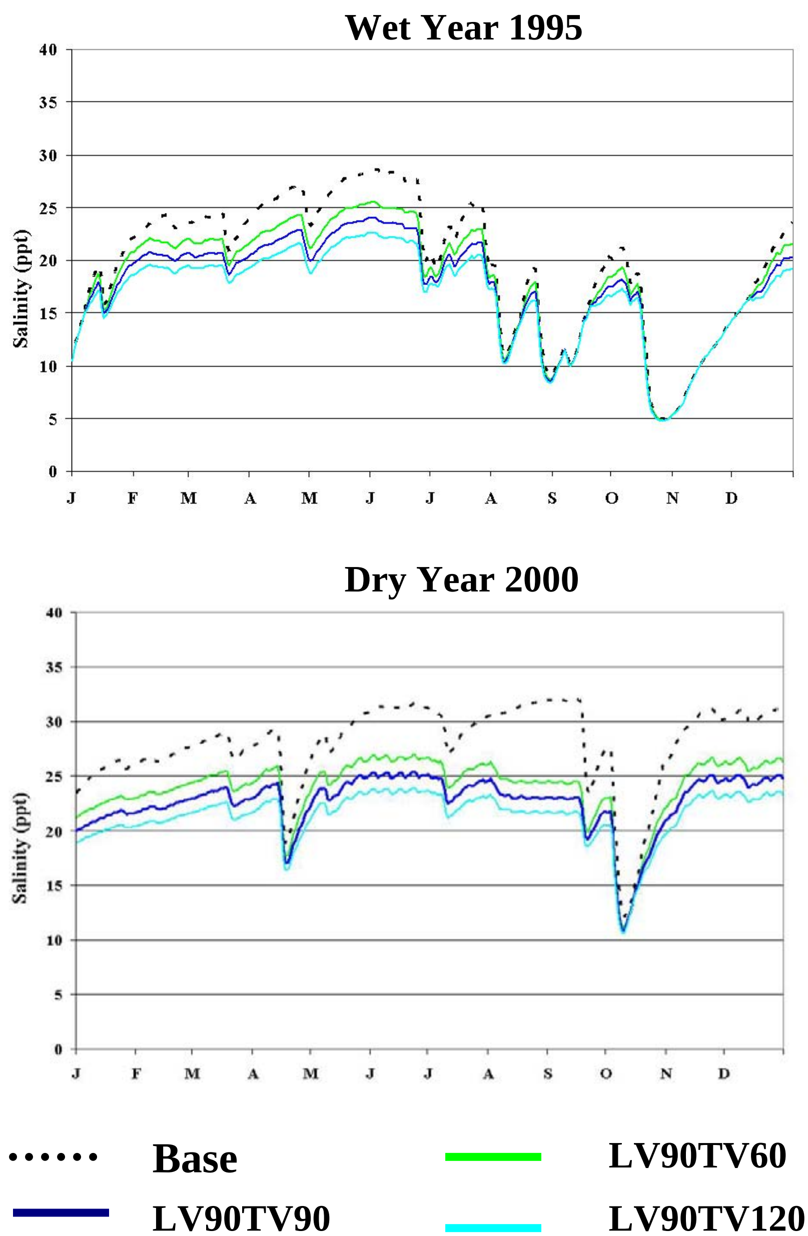


Figure 8-20. Comparison of Daily Average Salinity Conditions at Site 02 for Base Conditions and Three Variable Flow Runs.

Of the variability runs, **LV90TV60** was most similar to base conditions (**Figure 8-20**). During the wet year, when impacts to seagrasses from increased discharges would be expected to be greatest, **LV90TV60** was similar to the base conditions when salinities were low enough to impact seagrasses. At times when base conditions were "optimal" and **LV90TV60** salinities fell within the "potential stress" salinity range, the differences in salinity values were minimal (a few ppt). During the dry year, there was greater separation between the base run and **LV90TV60**. However, as with the wet year, the differences were at higher salinities where seagrass impacts would not be expected. At times when salinities were low enough to impact seagrasses the two model runs were very similar.

ANTICIPATED ECOLOGICAL CHANGE

The evaluation of the three variable flow scenarios with respect to the five VECs concludes that **LV90TV60** is the preferred restoration flow scenario. The probable vegetative changes in the tidal floodplains that would occur with **LV90TV60** are shown in **Figure 8-21.** Under this flow condition, the native freshwater vegetative communities in the riverine floodplain is anticipated be enhanced. The invasion of upland, transitional and exotic species onto the riverine floodplain will be discouraged. Also, this enhanced freshwater habitat should increase the occurrence of freshwater fish species such as largemouth bass *Micropterus salmoides*, and other fishes particularly from the Centrarchidae (sunfishes), Ictaluridae (catfishes) Cyprinidae (minnows) and Cyprinodontidae (killifish) families.

Due to the improved freshwater environment, a new Mixed Riverine Reach (light green shading) would be established between RM 10 (Moonshine Creek) and Kitching Creek (RM 8.1) in the upper tidal reach. Freshwater plant species (primarily bald cypress, pop ash and pond apple) would dominate at the canopy level and freshwater and saltwater species should be mixed at the subcanopy, shrub and ground cover levels. Other freshwater plant species such as red maple, buttonbush, swamp bay, and Carolina willow would occur less frequently while water hickory and other high bottomland hardwood species would probably be rare to absent due to the low elevations. The existing riverine communities at the back of the floodplains should improve in health and in recruiting freshwater plant species within the Mixed Riverine Reach.

A new Upper Tidal Transitional Reach (**Figure 8-21**, yellow shading) would be established between the mouth of Kitching Creek (RM 8.13) and RM 7.5. This new Upper Tidal Transitional Reach would consist primarily of a pond apple/ mangrove canopy with a mangrove/ leather fern understory. Pond apple seedlings appear to have a wider tolerance of flooding than bald cypress seedlings from our observance along the river and therefore should continue to tolerate the higher tidal amplitudes and greater periods of inundation within this reach.

A condensed Lower Tidal Reach (**Figure 8-21**, beige shading) may be established between RM 7.5 and RM 5.5. This reach would remain dominated by red and white mangroves due to tidal amplitude, low elevations, and the higher frequency of peninsulas and islands in the floodplains. Mangroves provide a significant source of primary production in their leaf litter and provide a major food source for detritivores in the estuarine food chain. This reach will also provide key habitats for recreationally important fish species such as common snook and saltwater fish larvae.

The increased flow under the preferred restoration scenario will increase the frequency of low salinity events. Habitat for fish larvae is still maintained in the lower tidal reach of the Northwest Fork. The increased flow may also eliminate some of the existing oyster beds between RM 5 and RM 6. The majority of oyster beds downstream RM 5 will remain. Potential impacts on seagrasses are considered to be minimal when compared with the base condition.

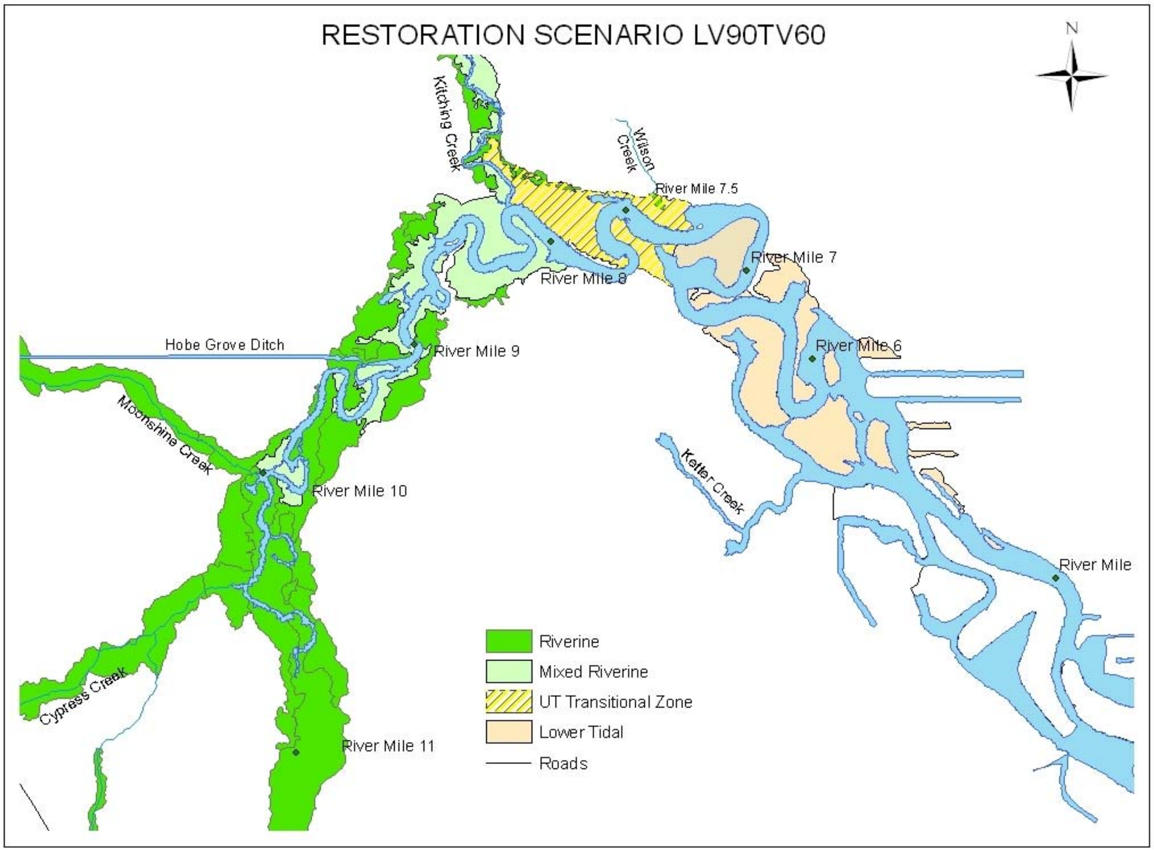


Figure 8-21. Expected Vegetation Changes in Response to the LV90TV60 Variable Flow Scenario.

SUMMARY

In response to the findings from the constant flow scenarios and public reaction to the results of the first five scenarios, three variable flow scenarios are developed to simulate a more natural, hydrological variability to achieve the restoration goal. The Preferred Restoration Flow Scenario incorporates both dry and wet season hydrologic flow patterns and provides the greatest ecological benefit to freshwater riverine and tidal floodplain VECs with minimal impact on the estuarine VECs. In this scenario, variable flow from Lainhart Dam includes both seasonal and short-term variability (daily and monthly). Supplemental flows are introduced during the wet season to achieve at 120 days of inundation of the cypress swamp in the freshwater riverine floodplain. In the dry season, supplemental flows are suggested to maintain a mean monthly flow of 65 cfs to 90 cfs for freshwater riverine floodplain hydration and to limit salt water intrusion to the downstream segments. On a daily basis, these flows emulate pulses of water from small rain events to benefit estuarine plankton communities. Supplemental flows from the remaining tributaries of 30 cfs are suggested when the total flow to the Northwest Fork is less than 300 cfs.

The Preferred Restoration Flow Scenario provides close approximations of optimal wet and dry season hydroperiods for cypress swamp in the freshwater riverine floodplain located between RM 16 and RM 9.5. In the freshwater riverine floodplain, the cypress swamp will be inundated for 4 to 8 months and the hydric hammocks will be inundated for about less than 30 days to 60 days in a year. During the dry season, water levels in the freshwater riverine swamp will drop and allow cypress seed germination. In the tidal floodplain, between RM 9.5 and RM 5.5, flows will push the saltwater front downstream from RM 9.5 to between RM 8 and RM 7.5. This will allow for recruitment of freshwater species in the upper tidal floodplain. Freshwater species will be expected to expand in number and dominate the canopy to the mouth of Kitching Creek near RM 8. There will also be recruitment of pond apple in the tidal floodplain due to the improvement in the freshwater environment near RM 7.5.

The Preferred Restoration Flow Scenario is also designed to minimize the impact on the estuarine ecosystems. The low salinity zone, located between RM 9.5 and RM 5.5, requires a salinity regime of 2 ppt - 8 ppt during the dry season to function as a nursery for many saltwater fishes. Although restorative flows will move the appropriate salinity range downstream, the low salinity will still remain within an area that will provide suitable habitat for juvenile fish development. The optimal salinity range for oysters is from 10 ppt to 20 ppt, which is currently located between RM 6 and RM 4. With increased flows during the dry season these salinity levels will be moved downstream and the upstream oyster beds at RM 6 will be lost. However, the majority of the oysters are located downstream of RM 5 and will not experience harmful drops in salinity levels. The addition of oyster substrate near RM 4 will mitigate the loss of oysters at RM 6. The Preferred Restoration Flow Scenario will have minimal impact on seagrasses in the Central Embayment area.

It should be noted that there are uncertainties involved with the evaluations. The current understanding of the ecosystem and the evaluation methods are based on best available data and analysis, which will be updated as more knowledge is gained regarding this system in the future. It is also unlikely that the future hydrological condition will follow exactly the same pattern as that in model simulations. Therefore, it is likely that the day-to-day system operation decisions will be based on the actual flow/stage and salinity readings from the monitoring stations with the freshwater flow versus salinity relationship provided by the model as a guideline. It is also anticipated that the system operation and ecosystem response in the future will take an adaptive management approach based on consistent system monitoring. Detailed operational procedures will need to be determined through adaptive management in the implementation stage of this plan. The ecosystem monitoring for Northwest Fork adaptive management is described in **Chapter 10**.

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Chapter 9

The Saltwater Barrier as a Restoration Alternative

INTRODUCTION

Managing freshwater flow to the Loxahatchee River and Estuary is the most natural way to manage salinity levels within the Northwest Fork. However, too much fresh water during the dry season can reduce the establishment of riparian tree seedlings within the floodplain and reduce plant diversity. Using a saltwater barrier may provide a supplemental means to manage salinity when freshwater amounts are inadequate or are needed for best management practices for the health of the river.

This chapter summarizes two previous proposals to place saltwater barriers in the Northwest Fork of the Loxahatchee River. A preliminary modeling study was conducted to examine the effectiveness of using two types of saltwater barriers in different locations for salinity management in the Northwest Fork. Based on the modeling results and the evaluation of the potential ecological impacts of the barrier system on the floodplain forest and estuarine communities, evaluations are made based on the location and type of barrier. The model simulations described in this chapter were conducted under average dry season flow conditions.

SUMMARY OF PREVIOUS SALTWATER BARRIER PROPOSALS

THE 1975 PROPOSAL

In 1975, the Jupiter Inlet District (JID) and Florida Department of Natural Resources (FDNR) applied to the U.S. Army Corps of Engineers for a permit to construct a saltwater barrier weir in the Northwest Fork near River Mile 6.0. The project would have involved the construction of a weir at an elevation 4-feet below mean sea level within the south boundary of Jonathan Dickson State Park (JDSP) and near an existing power line crossing. The weir would prevent a wedge of saline water from extending up river during the dry season. This project was planned to occur in conjunction with another permit application for removal of oyster bars near and under the FEC Railroad Bridge and the A1A Bridge.

The U.S. Fish and Wildlife Service (FWS) expressed concern that there was no hydrologic study that could confirm the effectiveness of such a weir structure in preventing saltwater intrusion. They recommended that the permit be denied until a hydrological analysis was made by the U.S. Army Corps of Engineers to demonstrate the effectiveness of the proposed weir. The FWS also recommended the study include other salinity management alternatives such as increasing freshwater flows and adding an inflatable structure on top of the proposed weir.

The U.S. Environmental Protection Agency (EPA), Region IV, also objected to the proposal. The EPA was not convinced that the proposed structure would prevent salt water from intruding upstream since the weir would be overtopped frequently by tidal action due to its low height. They were also concerned that the structure would trap salt water, allow organic material to be deposited behind the weir, and degrade water quality due to reduced tidal flushing. The permit to construct the saltwater barrier was not granted pending further study.

THE 1986 FEASIBILITY STUDY

In 1986, the Jupiter Inlet District (JID) initiated a study on the feasibility of using a barrier to limit saltwater intrusion upstream in anticipation of possible impacts upstream of the Loxahatchee River associated with the proposed inlet dredging program. This study investigated the need for and feasibility of placing one or more submerged weir(s) to limit the salinity intrusion that might result from the proposed Jupiter Inlet dredging. The study included a literature search on various types of installations for salinity control and identified potential sites within the Loxahatchee River for barrier placement. The literature search found that “little published information exists on the use or performance of submerged weirs for salinity control.” The feasibility report concluded that design of a submerged structure on the Loxahatchee River would require comprehensive study to verify its performance. Three sites were recommended as potential locations for the submerged weir salinity barrier: Island Way Bridges near River Mile 5.0; River Mile 5.5; and River Mile 6.0 (Cubit Engineering 1986).

PRELIMINARY MODELING EVALUATION OF SALINITY MANAGEMENT WITH SALTWATER BARRIERS

DEVELOPMENT OF A 3-D MODEL FOR HYDRODYNAMIC AND SALINITY SIMULATIONS OF SALTWATER BARRIERS

Saltwater barriers include many types of structures designed to prevent saltwater intrusion. The structures range from tide gates that can block out tide entirely to more common weir-type barriers that can be submerged during high tide. The simulation of a saltwater barrier requires a hydrodynamic computer model with special capabilities. When the tide falls below the crest of a saltwater barrier, fresh water from upstream will pour down the barrier crest and form a water fall. Such a flow phenomenon is called “supercritical flow” in hydraulics. Most existing hydrodynamic models, such as the RMA (USACE 1996), only simulate “subcritical flow” with a smooth water surface. To simulate supercritical flow over a saltwater barrier, a three-dimensional numerical model, CH3D, was modified to suit the task. The CH3D model is a non-orthogonal curvilinear grid hydrodynamic model that has been used in the Chesapeake Bay restoration study by U.S. Army Corps of Engineers and EPA. The boundary-fitted grid feature of CH3D is well suited for the Loxahatchee River where natural river channel patterns of bends and oxbows are preserved. The modified CH3D model covers the entire Loxahatchee River including the Southwest Fork, North Fork, and Northwest Fork. It also covers part of the Intracoastal Waterway north to St. Lucie Inlet and south to Lake Worth Inlet.

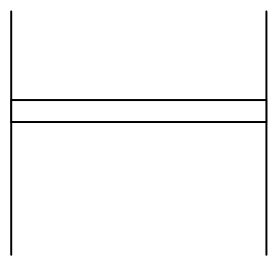
The modified CH3D model was verified using the most recent tide, flow, salinity and meteorological data collected by the South Florida Water Management District (SFWMD) and the U.S. Geological Survey (USGS). Then the model was used to study the relationship between freshwater flow and tidally averaged salinity at selected sites as a double check on the relationships that were established by previous 2-D model simulations (see **Chapter 6**, the RMA Model). The modified CH3D model was used to study the effectiveness of a proposed saltwater barrier to reduce the saltwater intrusion problem in the Loxahatchee River during the dry season. A number of design alternatives were modeled and results were evaluated to determine the effectiveness of each alternative.

Design of Salinity Barrier Alternatives

SALTWATER BARRIER TYPES

Two types of saltwater barriers were simulated. The Type 1 saltwater barrier has a single opening with barriers extending from each bank of the river. The opening was placed along the existing navigational channel. When the navigational channel is along the bank, only one barrier was needed. To model the Type 1 barrier, it has to be placed as one side of a grid cell that CH3D regards as an idealized thin barrier across which there is no flow.

The Type 2 saltwater barrier is inflatable and extends across the entire channel. Supercritical flow occurs over the Type 2 structure at low tide, the modified CH3D model is able to simulate this type of supercritical flow.



SALTWATER BARRIER LOCATIONS

Three barrier site locations were tested in the simulations (**Figure 9-1**). The first location (Location 1) is within the boundary of JDSP at RM 6.0 and represents the downriver edge of the existing oligohaline or low salinity zone ecozone. The second site (Location 2) is at the Island Way bridges (RM 5.0) and is located in the midpoint of the mesohaline ecozone. The third location (Location 3) is located near the sand bars at RM 4.0, and represents the upper edge of the polyhaline ecozone.

The locations of these simulation sites were chosen for modeling purpose only. The objective was to examine the difference of effectiveness of a barrier in each general area.

Figure 9-1. The Locations of the Three Saltwater Barriers Used for the Salinity Simulations within the Northwest Fork of the Loxahatchee River.

SALINITY BARRIER ALTERNATIVES

A total of 14 salinity barrier alternatives were simulated and are listed in **Table 9-1**. Alternative S0 represents the baseline condition with no salinity barrier. Alternatives S1 through S11 represent the use of one or more Type 1 barriers. For Type 1 barrier alternatives, the water depth at the opening was kept a minimum of 3.3 feet and the opening was kept at least 25 feet wide in order to meet the requirement for small craft navigation (State Organization for Boating Access 1996). Alternatives S12.1, S12.2, and S12.3 represent the use of a Type 2 (inflatable) barrier at Location 1. The difference between these three Type 2 alternatives is the crest elevation, the crest elevation for S12.1, S12.2 and S12.3 are –1.0, +0.1, and +1.0 feet NGVD29, respectively. For each of the 14 alternatives, the 2004 dry season was repeatedly simulated using the modified CH3D code developed by Coastal Tech. Each simulation run lasted 10 days.

Table 9-1. Description of the 14 Saltwater Barrier Alternatives Modeled in the CH3D Simulation for the Northwest Fork of the Loxahatchee River.

Alternative	Barrier Location	Barrier Type	Opening width (ft)	Depth at opening (ft, NGVD29)	Description
S0	--	--	--	--	No barrier
S1	1	1	100	Local depth	
S2	2	1	100	Local depth	
S3	3	1	100	Local depth	
S4	1	1	100	Local depth	Three barriers used (see **Figure 9-2**)
S5	1, 2 & 3	1	100	Local depths	Combination of S1, S2 & S3
S6	1	1	80	3.3	
S7	1	1	25	3.3	
S8	1	1	25	3.3	Three barriers used (Similar to S4, **Figure 9-2**)
S9	2	1	25	3.3	
S10	3	1	25	3.3	
S11	1, 2 & 3	1	25	3.3	Combination of S8, S9 & S10
S12.1	1	2	--	1.0	Crest elevation = −1.0 ft NGVD29
S12.2	1	2	--	0.1	Crest elevation = +0.1 ft NGVD29
S12.3	1	2	--	-1.0	Crest elevation = +1.0 ft NGVD29

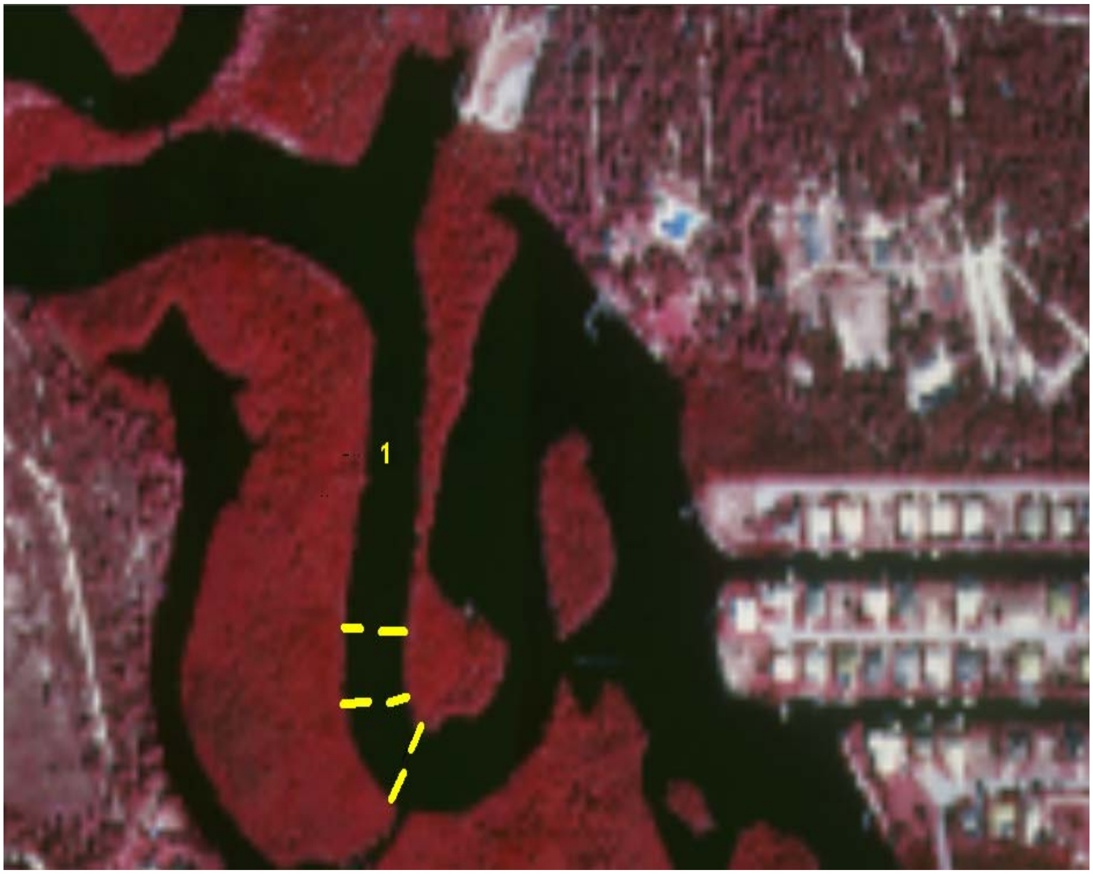


Figure 9-2. Placement of the Three Type 1 Saltwater Barriers at Location 1 for Alternatives S4 and S8.

Note: The actual placement locations of the three saltwater barriers were selected for modeling purposes only. The study objective was to examine the effectiveness of a series of barriers vs. a single barrier. These barriers may or may not be allowed within the boundary of the Wild and Scenic River.

Salinity Model Applications

Figure 9-3 shows the freshwater flows used as boundary conditions at S-46, Lainhart Dam, Cypress Creek, Hobe Grove Ditch and Kitching Creek for January 2004. To avoid tidal influences, the Kitching Creek USGS flow gauge was placed north of the mouth of Kitching Creek. Therefore it does not record all the runoff from the entire Kitching Creek basin. **Figure 9-4** shows the tidal elevation used at the open ocean boundary. The ocean open boundary condition for salinity was kept constant at 35.5 ppt when the flow is coming in (flood tide). During ebb tide, salinity at the open ocean boundary was computed by the model.

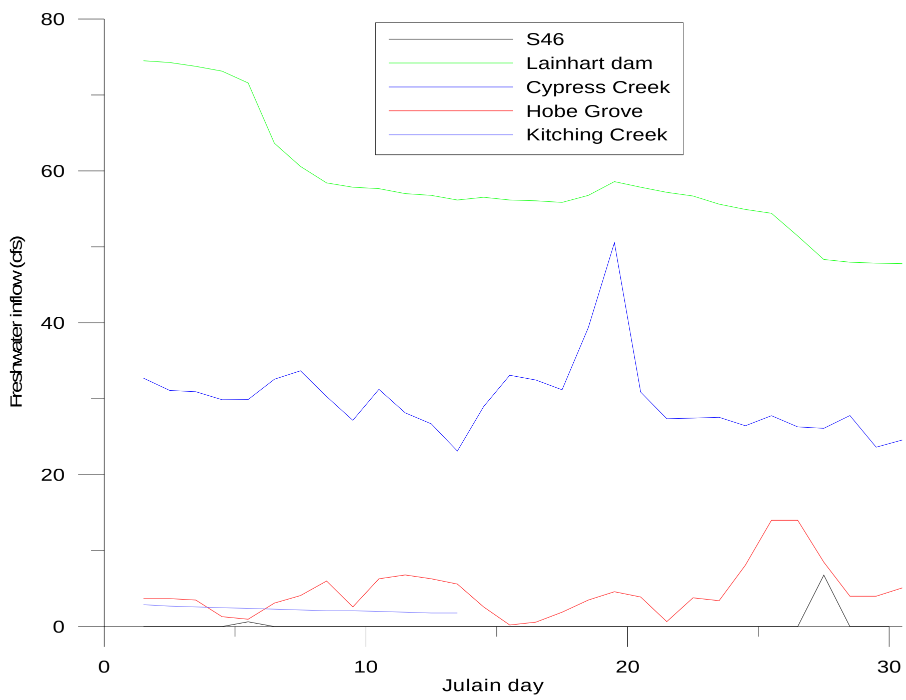


Figure 9-3. Freshwater Flows at S-46, Lainhart Dam, Cypress Creek, Hobe Grove Ditch, and Kitching Creek for January 2004.

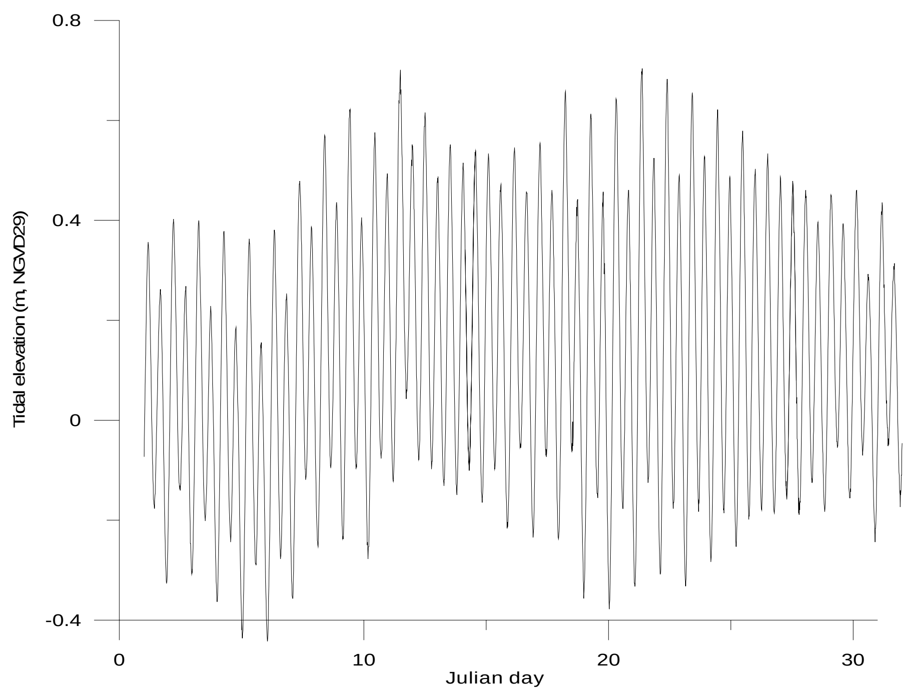


Figure 9-4. Tidal Elevation at the Coast Guard Station for January 2004.

The simulation of changes in salinity after introducing the 15 saltwater barriers alternatives was performed. The target range for the saltwater barrier performance simulation was to keep the salinity at River Mile 6.2 below 2 ppt.

TYPE 1 SALINITY BARRIER SIMULATIONS

Figure 9-5 shows the modeled salinity at RM 6.2 for Alternatives S0 through S5. For this group of alternatives, Type 1 barriers are used (except S0, which is the base condition for comparison). The central opening is 100 feet wide. In S1, S2 and S3, only one barrier is placed at each location. In S4, three Type 1 barriers are all placed at Location 1 (see **Figure 9-2**). And in S5, one Type 1 barrier is placed at each of the three locations. There is little reduction of salinity at River Mile 6.2 with any of these alternatives. Further upstream at Kitching Creek (RM 8.13; **Figure 9-6**), salinity reduction less than 1 ppt was seen for all the alternatives.

Figure 9-7 shows the modeled salinity at River Mile 6.2 for Alternatives S6, S7 and S8. For this group of alternatives, The Type 1 barrier is used only at Location 1. For these three alternatives, the width of the central opening was decreased from 100 feet (as used in Alternatives S1, S2, S3, S4, and S5) to 80 feet (S6) and 25 feet (S7 and S8). In S8, three barriers are placed at Location 1 (similar to S4, see **Figure 9-2**). Again, there is little reduction in salinity at River Mile 6.2. However, peak salinity at Kitching Creek (RM 8.13; **Figure 9-8**) is significantly reduced under Alternatives S7 and S8. This is because as the central opening at the barrier becomes increasingly smaller, the total salinity brought upstream by flood tide is significantly reduced leading to lower salinity at upstream locations after the initial 'jet' has dissipated.

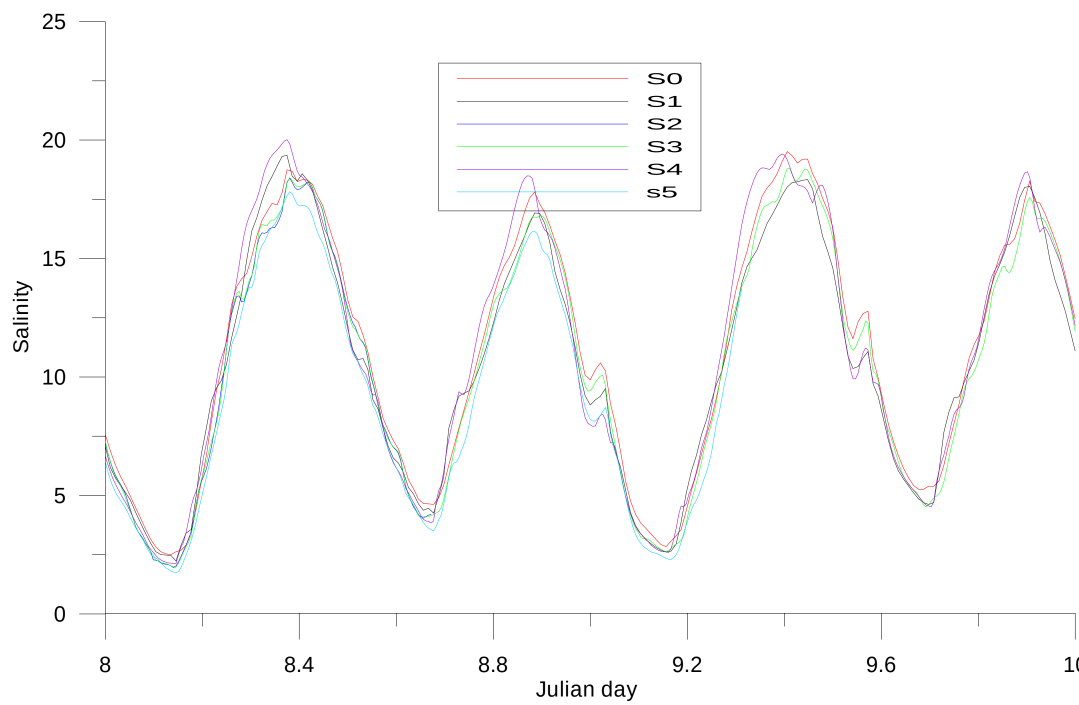


Figure 9-5. Simulated Upper Layer Salinity (in ppt) at River Mile 6.2 for Alternatives S0 to S5.

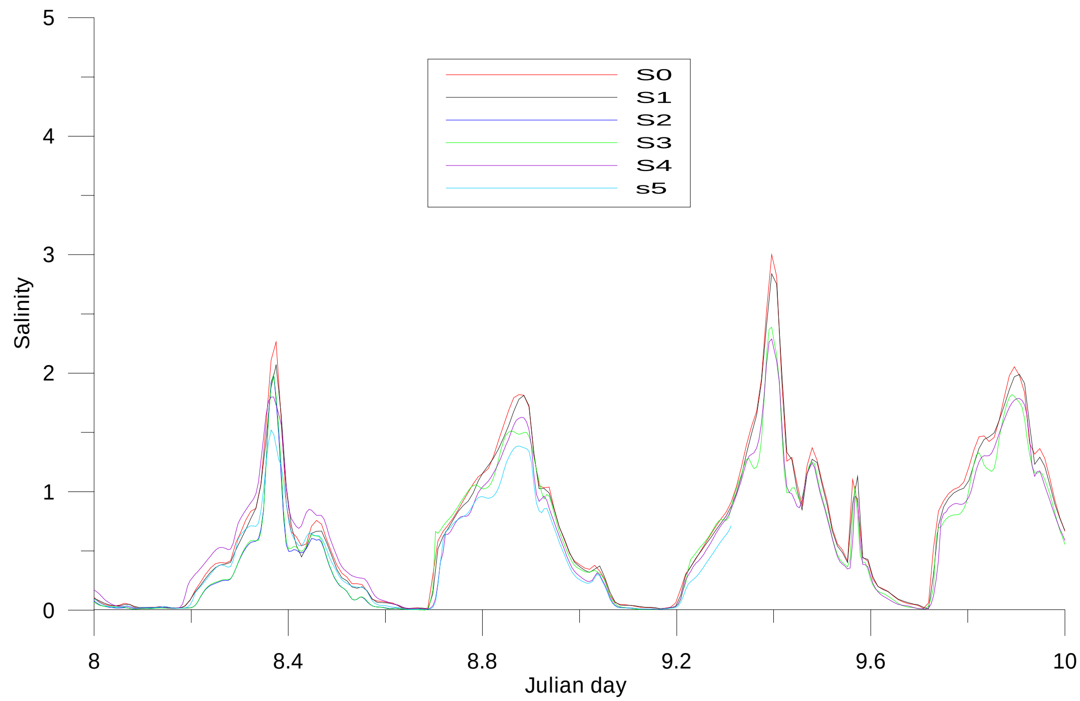


Figure 9-6. Simulated Upper Layer Salinity (in ppt) at Kitching Creek (RM 8.13) for Alternatives S0 to S5.

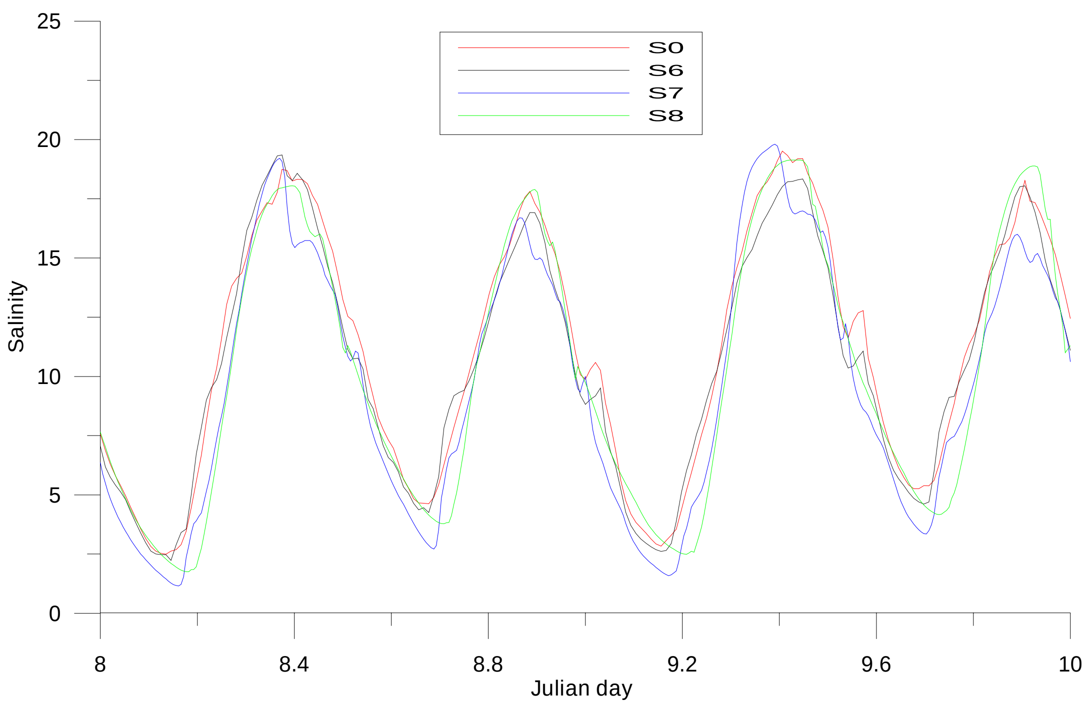


Figure 9-7. Simulated Upper Layer Salinity (in ppt) at River Mile 6.2 for Alternatives S6 to S8.

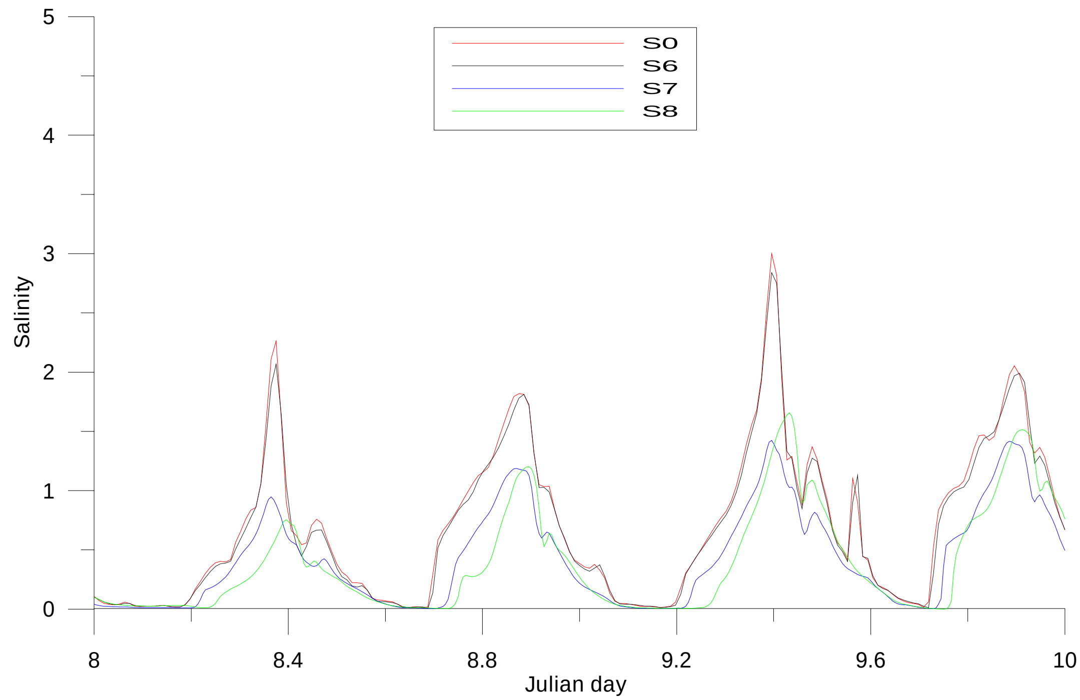


Figure 9-8. Simulated Upper Layer Salinity (in ppt) at Kitching Creek (RM 8.13) for Alternatives S6 to S8.

Figure 9-9 shows the modeled salinity at River Mile 6.2 for Alternatives S9 to S11. Alternatives S0 and S7 are also shown for comparison. For this group of alternatives, Type 1 barriers with 25-foot wide opening were used. In S7, S9 and S10, only one such barrier is used at each of the three selected sites. Alternative S11 is a combination of Alternatives S7, S9, and S10 (i.e., three barriers are used, one at each site). Little or no salinity reduction at River Mile 6.2 is seen for Alternatives S7 and S10. However, significant salinity reduction is seen for Alternatives S9 and S11. Salinity reduction is more significant in terms of percentage at Kitching Creek (RM 8.13; **Figure 9-10**) for all the alternatives. For Alternative S11, the most effective alternative, peak salinity reduction is approximately 25 percent at River Mile 6.2 and 80 percent at Kitching Creek (RM 8.13). Alternative S9 seems to be the most effective alternative for a single barrier placed at a single site. For S9, peak salinity is reduced by approximately 20 percent at River Mile 6.2.

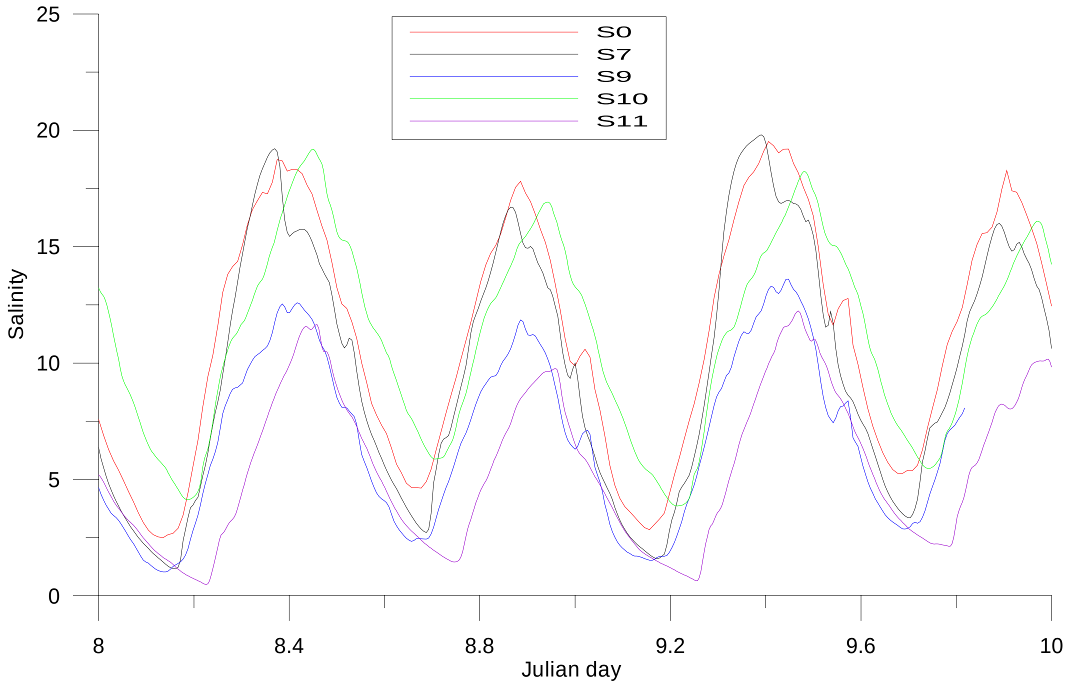


Figure 9-9. Simulated Upper Layer Salinity (in ppt) at River Mile 6.2 for Alternatives S7, S9, S10 and S11.

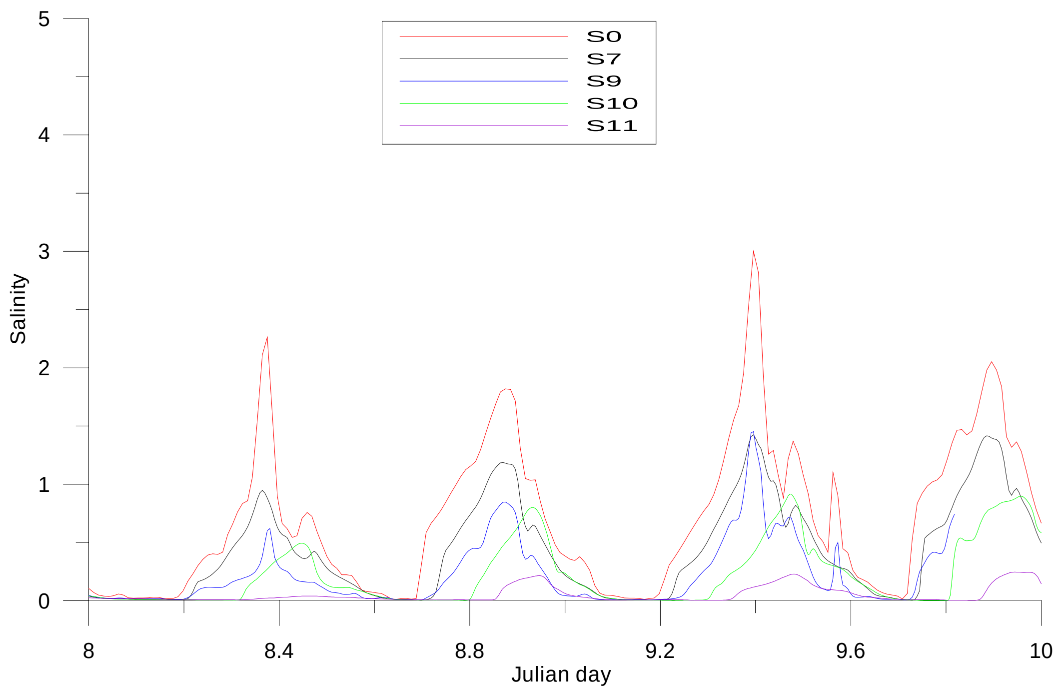


Figure 9-10. Simulated Upper Layer Salinity (in ppt) at Kitching Creek (RM 8.13) for Alternatives S7, S9, S10 and S11.

Summarizing the performance of Type 1 barriers, Alternatives S1 to S11, the simulation predicts significant salinity reduction when the width of the barrier opening was reduced to 25 feet. However, none of the simulations predict achieving the goal of keeping salinity at River Mile 6.2 lower than 2 ppt. By decreasing the width of the opening, the goal to achieve a salinity of less than 2 ppt at RM 6.2 should be possible, but there would be a likely negative impact to navigation for water craft. The minimum recommended navigable width requirement for small craft varies from state to state, but in most states, the minimum requirement is that the channel should be at least 20 feet wide and 3 feet deep at low tide. The simulation results suggests that using saltwater barriers in the Northwest Fork of the Loxahatchee River that meet this navigation requirement are not likely to achieve the specified goal for reducing salinity at River Mile 6.2 to less than 2 ppt.

TYPE 2 SALINITY BARRIER SIMULATIONS

Because Type 2 barriers extend across the width of the channel, navigation inevitably will be disrupted during the operation period. Using inflatable Type 2 barriers may alleviate some of the navigational disruption because they can be removed during the wet season when there is no need for saltwater barriers.

Figure 9-11 shows the modeled salinity at River Mile 6.2 for Alternatives S12.1, S12.2 and S12.3. As the crest elevation rises, the salinity at River Mile 6.2 decreases. Alternative S12.3 seems to nearly achieve the goal of salinity less than 2 ppt. At River Mile 6.2 it is less than 2 ppt throughout most of the tidal cycle except at high tide. Upstream at River Mile 7.0, the peak salinity is less than 2 ppt (**Figure 9-12**). Further upstream at Kitching Creek (RM 8.13), the water becomes almost fresh (**Figure 9-13**).

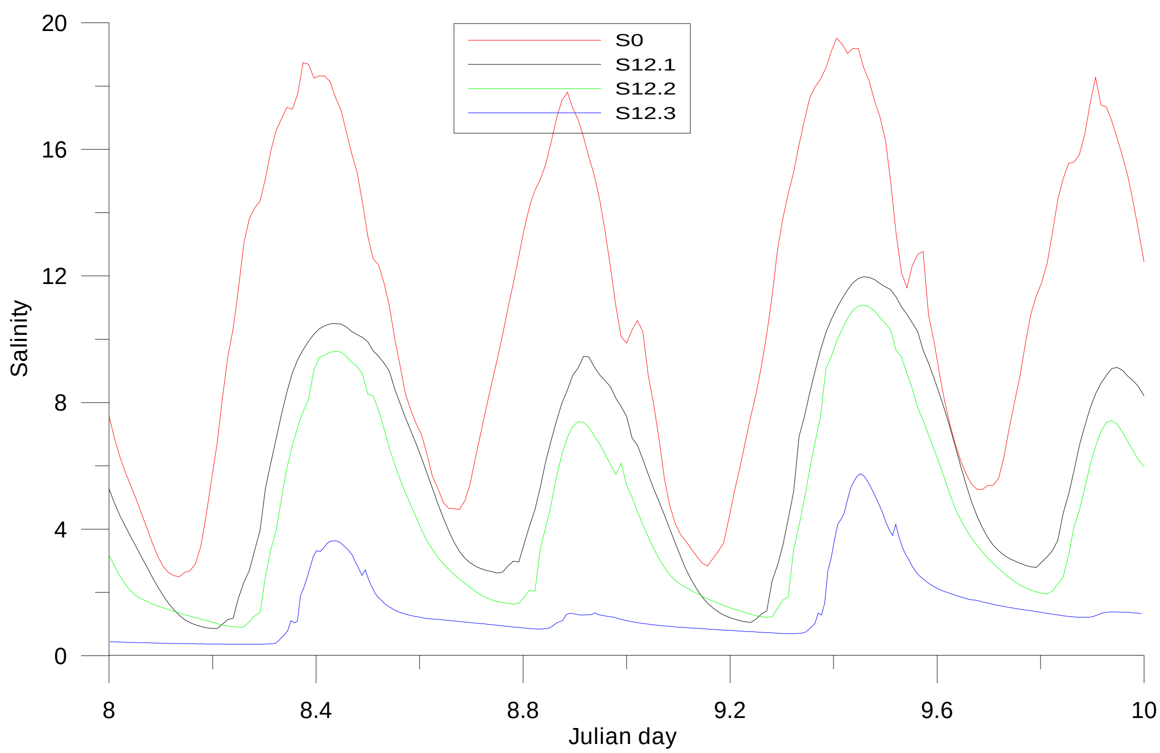


Figure 9-11. Simulated Upper Layer Salinity (in ppt) at River Mile 6.2 for Alternatives S12.1, S12.2 and S12.3.

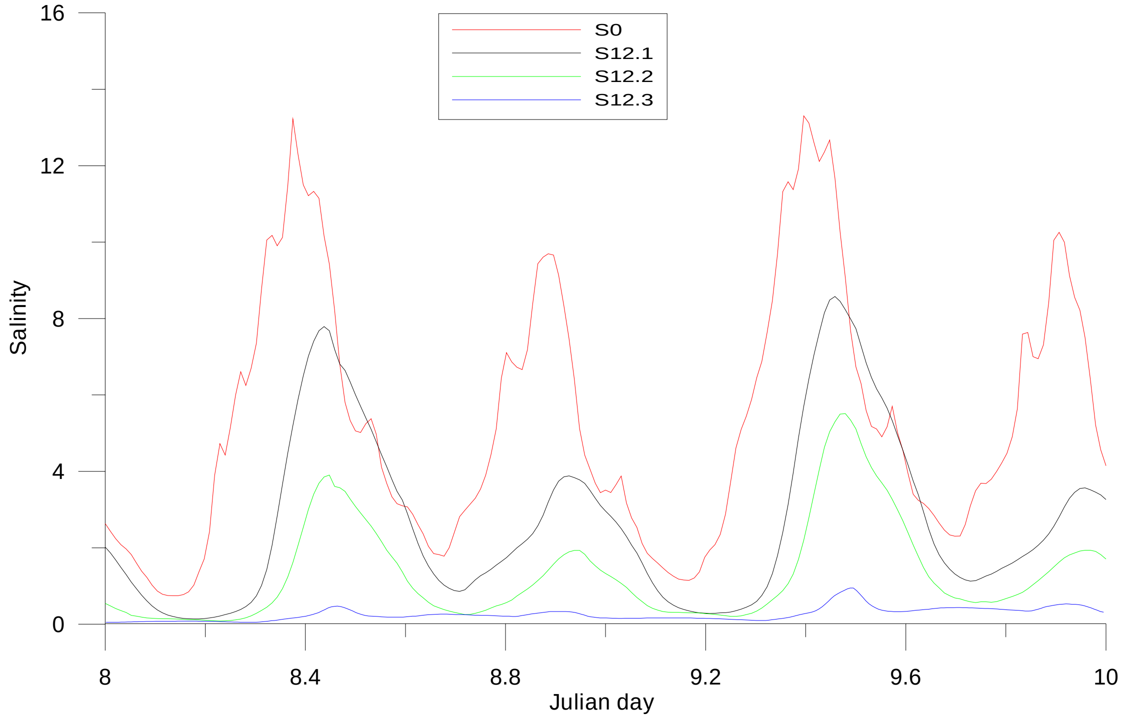


Figure 9-12. Simulated Upper Layer Salinity (in ppt) at River Mile 7.0 for Alternatives S12.1, S12.2 and S12.3.

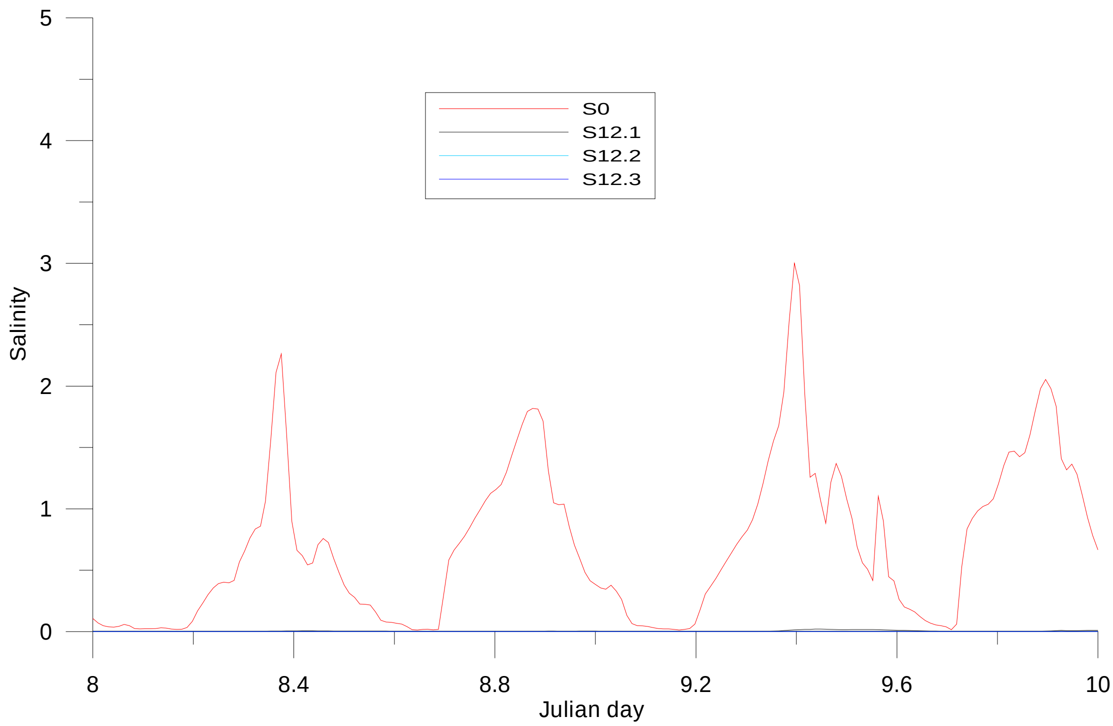


Figure 9-13. Simulated Upper Layer Salinity at Kitching Creek (RM 8.13) for Alternatives S12.1, S12.2 and S12.3.

Because of the relative effectiveness of the Type 2 barriers in reducing saltwater intrusion, their impact on water level (**Figure 9-14**) and flow rate (**Figure 9-15**) was compared with the base condition, S0. Tidal range is greatly reduced with the presence of the saltwater barrier (**Figure 9-14**). Tidal range is less than 0.5 feet for Alternative S12.3 compared with tidal range of nearly 3 feet for the existing condition (S0). Flow rate is also greatly reduced as it is blocked by the barrier.

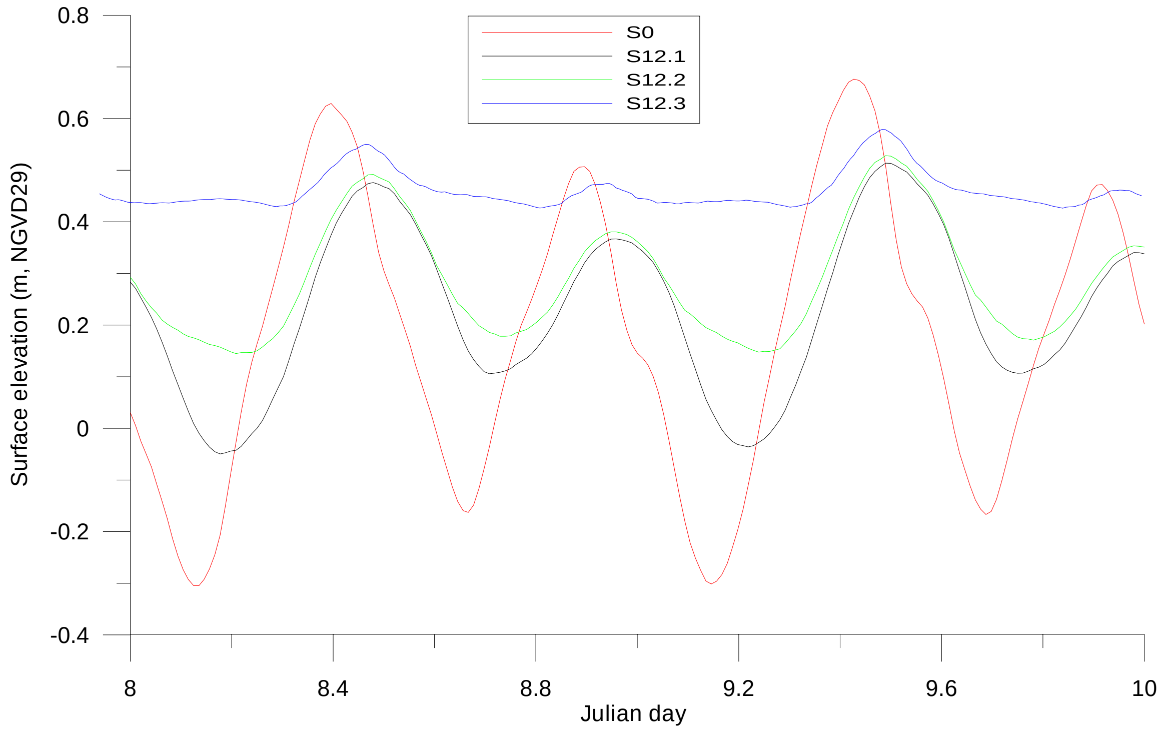


Figure 9-14. Simulated Water Surface Elevation at River Mile 6.2 for Alternatives S12.1, S12.2 and S12.3.

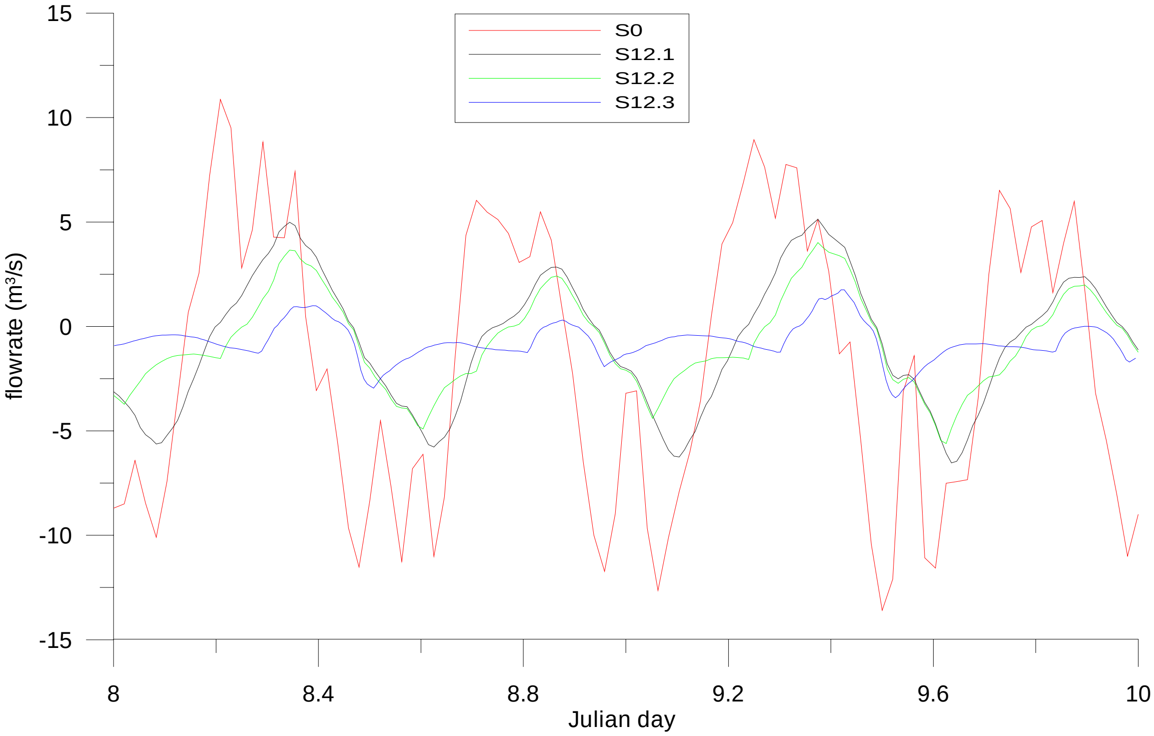


Figure 9-15. Simulated Flow Rate at River Mile 6.2 for Alternatives S12.1, S12.2 and S12.3. Flood tide +; Ebb tide -.

EVALUATION OF SALINITY BARRIER ALTERNATIVE MODELS

In summary of the performances of all the alternatives, **Table 9-2** lists the peak salinities at Boy Scout Dock (RM 5.92) and Kitching Creek (RM 8.13) during the period from Julian day 8 to 10 as predicted by the CH3D model. The lower the peak salinity, the more effective the alternative is. Another measure of the overall performance is the total salinity transported upstream of Boy Scout Dock. The better performing salinity reduction alternatives will transport less salinity upstream. The 6th column of **Table 9-2** shows the total salinity transported upstream at Boy Scout Dock during flood tide for the period from Julian day 8 to 10, 2004. All of the alternatives offer some degree of salinity reduction relative to the existing condition (S0). However, alternatives using the Type 2 barrier are significantly more effective in reducing salinity than are the alternatives using a Type 1 barrier.

Table 9-2. Comparison of the Performance of the Salinity Barrier Alternatives on Julian Days 8 to 10, 2004.

Alternative	Barrier		Peak Salinity (ppt)		Total salinity transport (kg)
	Location	Type	BSD	KC	
S0	--	--	19.51	3.00	2,100,836
S1	1	1	19.61	2.29	2,067,592
S2	2	1	15.55	0.92	1,541,236
S3	3	1	18.40	1.99	1,928,816
S4	1	1	20.01	2.26	1,997,935
S5	1, 2 & 3	1	14.88	1.57	1,557,198
S6	1	1	18.83	1.98	2,045,861
S7	1	1	19.81	1.42	1,786,714
S8	1	1	19.14	1.66	1,640,093
S9	2	1	13.60	1.45	1,295,635
S10	3	1	14.17	0.30	998,579
S11	1, 2 & 3	1	10.75	0.17	661,928
S12.1	1	2	11.97	0.03	630,869
S12.2	1	2	11.08	0.00	465,165
S12.3	1	2	5.80	0.00	102,148

Based on the results of this model simulation, we conclude that a weir raised to an elevation one foot above the mean tide is the most effective barrier type for salinity reduction in the Northwest Fork. This barrier can be effective at the immediate upstream if the crest elevation was higher than high tide.

For saltwater barriers with an opening to be effective, the width of the opening needs to be small. Barriers with 25-foot wide openings (the minimum allowable channel size for small watercraft) performed better than barriers with larger openings. Based on model simulations using barriers with an opening, salinity is not significantly reduced until approximately 1 mile upstream of the barrier.

ECOLOGICAL CONSIDERATIONS OF THE TYPE 2 SALINITY BARRIER

Using a salinity barrier that spans the full width of the Northwest Fork of the Loxahatchee River downstream from RM 6.0 offers significant salinity reduction. However, there are significant ecological concerns that also need to be addressed regarding the use of a saltwater barrier as a possible restoration alternative. Several questions have been raised though District staff's communications with the Park Service of FDEP (Roberts 2004):

1. In the process of feasibility study, water quality needs to be considered, especially the location of the structure in relationship to stormwater run-off areas.
2. Should there be a concern about nutrient concentrations and possible algal problems occurring behind the structure?
3. A saltwater barrier can cause both a temperature and dissolved oxygen imbalance in and around its vicinity.
4. The barrier structure will have an effect on the spawning and nursery areas for fish. Some type of "fish ladder" device will certainly be required by U.S. Fish and Wildlife Services.
5. There also will be concern about localized flooding when a weir type structure is built on the river.
6. Recreational boat traffic will need to be minimally impacted if the project is to succeed.

Discussions of some of these questions as they relate the Type 2 barrier are presented in the following sections.

ECOLOGICAL FRAGMENTATION

A paramount concern of using the Type 2 barrier is that, although this barrier is most effective for saltwater intrusion control, it would cause fragmentation of the estuary ecosystem by seriously reducing the area of essential, low salinity zone (LSZ) nursery habitat available to juvenile estuarine and marine fish and shellfish, and causing significant declines in fish abundance and diversity above the barrier (Mallen-Cooper 1999). This loss of essential habitat could have a negative impact on the success of the year class of those species dependant on this estuarine nursery function during the dry season (North and Houde 2001). These species include fishes popular with anglers, such as snook and redfish; those used commercially, such as eels and blue crabs; those species important in the estuarine food chain such as bay anchovies, mullet, gobies and mojarras; and threatened species such as the opossum pipefish. Furthermore, many tropical species that frequent the Loxahatchee estuary, such as five species of snook, seek the warm groundwater temperatures in the inner estuary during cold events. The Type 2 barrier would prevent these tropical species from migrating upstream to this warm water refuge during the winter.

Once the barrier is in place, the normal inner estuary tidal flushing, about 2 feet of amplitude, will be minimized. This tidal flushing normally transports runoff and also inundates and drains a portion of the vegetated floodplain which consistently exports particulate organics and dissolved nutrients to the estuary. These substances are required for successful, healthy phytoplankton and zooplankton populations to nourish juvenile and adult fish and shellfish (oysters), the anticipated reduction of these substances from the inner estuary may reduce overall estuarine productivity and nursery function. Additionally, the retention of these substances upstream of the structure may provide suitable water quality conditions for harmful algal blooms.

WATER QUALITY

Because the Type 2 saltwater barrier only allows flows out of the inner estuary, the water quality and hydrology upstream and downstream of the saltwater barrier may be affected. Extensive surface water quality monitoring of the Northwest Fork of the Loxahatchee River is being conducted by the Loxahatchee River Environmental Control District (LRD). In consultation with LRD staff, the most significant water quality issues that would be encountered with a saltwater barrier would be the lack of surface water circulation and deposition of muck and other sediment immediately behind the structure. This would affect several water quality parameters including water temperature, dissolved oxygen, total suspended solids, water clarity, turbidity, tannins, total organic carbons, chlorophyll, fecal coliform bacteria, pesticides, and herbicides. The stagnant water conditions created by the barrier would lower dissolved oxygen and water clarity, and raise the water temperature.

Dams serve as settling basins for pollutants. Of concern with a temporary inflatable structure would be the effect on water quality immediately after the deployment period ends. When the structure is removed, sediment plus the pollutants that fall out into that sediment immediately behind the structure would be carried downstream into the estuary and eventually offshore to the reef systems over a short period of time.

Thermal stratification would occur behind the structure and negatively impact dissolved oxygen concentrations by preventing the mixing of the two water layers. The bottom water layer would become trapped and have no contact with the air. The oxygen in the lower layer would be gradually depleted as organic material that has been washed downstream settles to the bottom and decays (Tennessee Valley Authority 2004). The depletion of dissolved oxygen and increase in Biological Oxygen Demand (BOD) are harmful to aquatic plants and animals.

Water temperatures can have significant effects on health, distribution, and abundance of fish, amphibians, aquatic insects, benthic organisms, and aquatic plants (Washington State Department of Ecology 2004). Water impounded behind a dam has higher water temperatures than water in a free flowing river; the dam exposes more surface water area to solar and air temperature influences. Higher water temperatures can trigger algal blooms, excessive growth of aquatic macrophytes, and fish diseases.

Elevated levels of turbidity and total suspended solids can reduce water clarity. Increased turbidity can also clog gills; stimulate organism avoidance behavior; reduce the ability to find food; reduce the rate of photosynthesis and primary production; and smother benthic organisms, spawning areas, and habitat (Washington State Department of Ecology 2004).

Nutrients are important for the growth of plants and algae in the river and estuary system. The effect of a salinity barrier on the amount of nutrients available for the estuary ecosystem during the periods of deployment is unknown. However, the rate of nutrient loading into the estuary may be temporarily increased when the salinity barrier is removed. This short-term nutrient enrichment can have an adverse impact on aquatic ecosystems. By adding chemical sealants to the sediments, this may help promote a slower, steady release of nutrients when the barrier is removed.

Fecal coliform bacteria are used as indicators of the presence of bird and mammal (including human) feces. The Northwest Fork of the Loxahatchee River has experienced high levels of fecal coliform bacteria in the past; this has resulted in closures of the Jonathan Dickinson State Park Public Swimming Area. Adding a dam structure to the river may increase the levels of fecal coliform bacteria as a result of reduced tidal flushing. Fecal coliform bacteria levels are generally lower in saline waters and are eventually destroyed by saline waters within the lower estuary and Atlantic Ocean.

The Washington State Department of Ecology (2004) recommended that as part of a formal compliance schedule for a dam that a water quality attainment plan be established to ensure the highest attainable water quality conditions at a structure. The water quality attainment plan should address current water quality standards, possible causes of impairment, monitoring considerations, and protection and improvement actions. Chapter 3 of the Guidance Manual provides a technical overview of many water quality parameters of concern, monitoring considerations, and some possible solutions to correct water quality problems.

FLOODPLAIN VEGETATION COMMUNITIES

As discussed in **Chapters 3** and **4**, the tidal floodplains of the Northwest Fork of the Loxahatchee River consist primarily of mangrove and pond apple swamp and sabal palm hammock communities. One concern with using the Type 2 saltwater barrier would be the ability to produce an occasional dry-dry season for freshwater deciduous seed germination and seedling/sapling growth. Because of the reservoir effect produced by the barrier and the low elevations of the floodplain in the tidal reaches, the floodplain areas with elevations lower than mean high tide would possibly remain flooded throughout the dry season. The critical periods for germination and seedling sapling growth (November-April) correspond to the dry season, which is the same time period that the saltwater barrier would be used to effectively control saltwater intrusion. Also, the higher water levels would change the short-term character of the groundcover and shrub communities to the advantage of plant species that are better adapted to flooding conditions. Those species that are not tolerant of flooding could become stressed or die. A major focus of the restoration plan for the Northwest Fork of the Loxahatchee River is to promote the return of freshwater canopy, shrub and groundcover species to the areas that have been invaded by red and white mangroves.

Although placing a Type 2 barrier across the entire river provides the most significant reduction in saltwater intrusion, the potential ecological impacts are an obvious concern. However, using a Type 1 barrier that allows for some flow through the barrier provides significantly less reduction of saltwater intrusion. Additional reductions in saltwater intrusion might be achieved with improvements in the configurations, numbers, and locations of Type 1 barriers. Concerns about ecological fragmentation, water quality, and floodplain vegetation could be reduced as optimization of Type 1 barriers is achieved.

CONCLUSIONS

Based on the preliminary modeling evaluations, it is concluded that an inflatable weir (Type 2) raised to an elevation one foot above the mean tide that spans the entire width of the river channel is the most effective barrier for salinity reduction in the Northwest Fork of the Loxahatchee River. Because all of the simulations were conducted under the same hydrological conditions, comparisons between weir type and weir location are appropriate. As other restoration projects are implemented and dry season freshwater flows increase, it is possible that a weir alternative that was considered less effective in this assessment scenario may be sufficient under alternate freshwater flow conditions. Therefore additional modeling studies may be necessary when considering a saltwater barrier, combined with other restoration measures.

However, extreme caution must be used before a saltwater barrier is considered as a restoration option; the potential adverse impacts on the ecosystem, boat navigation, and recreational activities in the Northwest Fork may outweigh the benefits. Additionally, the saltwater barrier should only be considered if additional sources of water supply will not be available for restoration flows in the dry season. In addition, the selection of barrier types should be carefully considered to allow for salinity management, flood control, navigation, and recreational use of the Loxahatchee River. Also, flexibility in operation is required so that if the water quality above the barrier decreases due to the reduced tidal circulation, the barrier can be quickly removed and the water quality restored. An inflatable weir seems to offer the flexibility to preserve the conveyance of the existing river channel and reduce negative impacts on flood control during the wet season. However, this has to be exercised with a precise operational schedule, taking into account the possibility of ecological segmentation and increases in salinity when the barrier is partially deflated.

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Ecological Monitoring for Adaptive Management

INTRODUCTION

The Preferred Restoration Scenario identified for the Northwest Fork of the Loxahatchee River Restoration Plan was developed with available data and analysis techniques successfully used to create water management guidelines for similar ecosystems. The integration of predictive results from watershed, hydrodynamic/salinity and biological models in concert with information from recent field investigations provided the basis for evaluating potential impacts of various flow scenarios on Valued Ecosystem Components (VECs) and their Performance Measures (PMs).

Without past efforts to document various physical, chemical and biological parameters in the watershed and receiving waterbody, a Preferred Restoration Scenario could not have been developed to the level of certainty accomplished for this Plan. During plan development the value of existing monitoring programs was evaluated to support the new restoration flow scenario. If the new restoration flow scenario is adopted, it will be implemented in a step-wise fashion as restorative flows are provided. All new information obtained should be focused on our ability to assess biological and hydrological affects of our water management methods as new facilities become operational. Using this information, we can adaptively manage flows and proceed toward our goal of achieving a healthy ecosystem.

Effective monitoring of the Northwest Fork ecosystems will require adjustments to several existing monitoring programs and the addition of new scientific programs to assure the information obtained will promote beneficial water management methods. A Northwest Fork Science Plan (NWFSP) will be developed based on specific scientific questions that need to be answered to manage restoration flows. Once the appropriate questions are identified by the NWFSP, specific monitoring programs and special projects can be designed and implemented. These monitoring programs will provide the information needed to successfully manage restoration flows on a real-time basis and establish a database for retrospective and predictive analyses. To assist in this effort, the Comprehensive Everglades Restoration Plan, Monitoring and Assessment Plan, Part 1 (CERP 2004) for the Loxahatchee Estuary includes some important monitoring programs that will be incorporated into the NWFSP.

The Northwest Fork Science Plan will guide future scientific efforts for the next five years and will enable the efficient application of limited resources to prioritize infrastructure, water management and monitoring projects. The NWFSP will be developed by the scientists and engineers associated with the development of the Preferred Restoration Scenario and shared with other agencies and the public. This Restoration Plan presents recommendations to continue current monitoring programs, develop additional monitoring programs, and implement special short-term studies. All of these recommendations will be reviewed in context of the NWFSP. As a coordinated, scientifically based understanding of the ecosystem response to water management evolves, adaptive management decisions will be scientifically justified and documented. A report compiled by all involved parties will update the progress of our adaptive management techniques and the NWFSP every five years.

This chapter identifies the systemwide and ecosystem-specific monitoring programs necessary to measure water flows, vegetation and wildlife changes, and changes in other constituents. The data collected from these programs will be used to protect and restore the freshwater floodplain, tidal floodplain and the estuarine reaches of the Northwest Fork of the Loxahatchee River. Monitored parameters, locations, frequencies and rationales will be discussed.

Monitoring programs should provide the data and information necessary to do the following:

1. Characterize the condition of each of the river reaches in terms of:
   a. Flows and associated water stages, duration, and timing,
   b. Water quality criteria such as salinity and other constituents,
   c. Select flora,
   d. Select fauna.
2. Observe changes in monitored constituents on an ongoing basis.
3. Measure and quantify changes and trends in the monitored constituents during the restoration activities.
4. Support ongoing and future modeling activities.

NORTHWEST FORK SYSTEMWIDE MONITORING

RAINFALL DATA

The current, nine rainfall gauging stations within the watershed are maintained by the SFWMD and provide adequate data to model surface water runoff to the Loxahatchee River. Additional rainfall data at six other locations in the watershed are available from the Loxahatchee River District (LRD) Wild Pine Laboratory.

Recommendation – The SFWMD rainfall gauges are part of a regional data collection network and should be maintained to support the adaptive management of the Loxahatchee River Watershed.

WATER QUALITY

From about 1970 to 1990, water quality monitoring in the Loxahatchee River was limited to dissolved oxygen, salinity, pH, turbidity, and temperature and was performed by the U.S. Geological Survey (USGS), Florida Department of Environmental Protection (FDEP), SFWMD, and LRD. In the 1990s, the LRD began the “RiverKeeper” project that provided for a bi-monthly comprehensive water quality (30 parameters) sampling program at 43 sites. These sites are located in the three major forks of the Loxahatchee River and in tributaries to the Northwest Fork (**Appendix G**).

In 2004, the LRD and SFWMD established interim water quality targets for three segments of the Northwest Fork and the Florida Park Service (FPS) at Jonathan Dickinson State Park (JDSP) assisted in developing interim water quality targets for the Wild and Scenic portion of the Northwest Fork. These target values are averages of eight years of data. The water quality target values for salinity zones are identified in **Table 10-1** with sample sites depicted in **Figure 10-1**.

Recommendation – The existing water quality program was designed to identify long-term trends related to State water quality standard compliance and self-imposed water quality targets. The NWFSP will address additional objectives needed to adaptively manage the system. Once the NWFSP is complete, specific recommendations for future efforts can be considered.

Table 10-1. Water Quality Target Values for Salinity Zones in the Loxahatchee River Estuary.

Water Quality Parameter	Loxahatchee River and Northwest Fork Stations				
	Estuarine Reach		Tidal Floodplain	Riverine Floodplain	
	Marine	Polyhaline Ecozone	Mesohaline/ Oligohaline Ecozones	Wild & Scenic Reach	Fresh Water Tributaries
	Stations 10, 20, 30	Stations 51, 60, 72	Stations 62, 63, 64	Stations 67, 68, 69	Stations 81, 95, 100
Temperature(◦C)	25.4	25.4	24.3	24.1	24.4
pH (units)	7.83	7.69	7.56	7.37	7.44
Alkalinity (mg/L)	117	115	135	159	146
Salinity (ppt)	31.5	23.9	7.6	0.5	0.5
Specific Conductivity (umho/cm)	48.2	37.7	12.1	0.5	0.5
Color (PCU/units)	18	46	61	64	63
Total Suspended Solids (mg/L)	6.8	6.1	4.2	4.1	4.4
Turbidity (NTU)	2.7	3.0	2.1	2.3	2.5
Secchi Disc (Meters)	1.74	1.27	1.39	1.10	1.26
P.A.R. @ 1M (%)	61.7	40.1	21.6	--	--
Dissolved Oxygen (mg/L)	6.53	6.41	5.54	5.30	6.21
Dissolved Oxygen Saturation (%)	94.8	89.2	67.5	63.5	70.7
Total Phosphorus (μg/L)	25	38	56	46	51
Total Nitrogen (mg/L)	0.98	1.31	1.41	0.99	1.03
Ammonia Nitrate (mg/L)	0.058	0.072	0.065	0.087	0.077
Chlorophyll a (μg/L)	3.45	8.02	4.74	2.94	4.79
Fecal Coliform Bacteria CFU/100mL	17	99	211	282	325

Figure 10-1. Selected Loxahatchee River District (LRD) Water Quality Sampling Stations in the Loxahatchee River Watershed.

GROUNDWATER MONITORING

In 2003 the SFWMD installed 12 shallow groundwater monitoring wells in Jonathan Dickinson State Park (JDSP) along Vegetation Transect 1 (RM 14.5), Transect 3 (RM 12.07), Transect 7 (RM 9.10), Transect 8 (on Kitching Creek) and Transect 9 (RM 6.46). Electronic monitoring at 15- to 20-minute intervals measured stage, temperature and conductivity. These data are essential to document hydroperiods and saltwater movement within the groundwater of the upper and lower tidal floodplains so they can be related to changes in vegetation. Additionally, these data are being used by the SFWMD to develop a model that predicts groundwater movement and quality.

Recommendation – Long-term monitoring of the groundwater wells needs to continue with the long-term monitoring of river channel stage and salinity.

LAINHART DAM FLOW

Of the four tributaries that contribute to the Northwest Fork, the largest portion of flow is from the Lainhart Dam. Since 1977 the USGS has been monitoring water stage immediately upstream of the Lainhart Dam and estimating flows (published annually) from a stage/flow rating curve developed at that time. The SFWMD also started monitoring stage at the same location in 1977 to calculate real-time flows for management purposes. In 2004, District Technical Publication, SHDM #1, Rating Improvements for Lainhart Dam by Juan A. Gonzalez revisited the rating curve established in 1977, and recommended periodic updates to maintain appropriate levels of accuracy.

Recommendation – Documenting real-time flow from Lainhart Dam is essential to adaptively manage the system and provide information to enhance all of the predictive models. Additional upstream monitoring of stages at existing vegetation transects and flows to the waterway need to be considered in the NWFSP.

OTHER TRIBUTARY FLOWS

The composite flow from the three additional tributaries downstream of Lainhart Dam also needs to be monitored. For this reason, stage recorders were installed outside of the region of tidal influence at Kitching Creek (since 1979), Cypress Creek and Hobe Grove Ditch (since 2002).

Recommendation – Flows from each tributary must be monitored to capture the relative contributions and subsequent effects on the tidal floodplains and salinity in the estuary. Additional gauges will be considered in the NWFSP relative to potential restoration activities within these tributaries.

TIDE AND SALINITY MONITORING

Since 2002, tidal stage and salinity have been monitored in the Northwest Fork and estuary by USGS, SFWMD, and LRD (**Appendix G**) to support model development and other analyses. Ocean boundary conditions for the estuary salinity model (RSM) are based on tidal and salinity data collected at the USGS Coast Guard station (RM 0.70) is in Jupiter Inlet. The salinity station in the Central Embayment (RM 1.77), where most of seagrasses are located, is affected by flows from all the major tributaries with a large portion often provided from the Southwest Fork at S-46 on C-18. The other three stations (RM 5.92, RM 8.13, and RM 9.1) are in the Wild and Scenic River portion of the Northwest Fork where saltwater intrusion is a main concern. Since January 2004, the LRD, in cooperation with the SFWMD, monitored five additional stations. Two of the stations are located in the Central Embayment to enhance observations near seagrass beds, whereas the other three locations provide addition information for modeling and biological investigations.

Recommendation – Real-time monitoring is critical in the Wild and Scenic River portion of the Northwest Fork to successfully manage restoration flows. The SFWMD needs to install instrumentation at two locations to allow operators at the West Palm Beach headquarters to observe salinity and manage control structures in accordance with the plan.

FLOODPLAIN ECOSYSTEM MONITORING

ANIMAL MONITORING

An assessment and monitoring program based on adaptive management principles can provide information to understand changes and make appropriate decisions regarding the use and maintenance of resources and biodiversity in the ecosystems (Spellerberg 1991, 1992; Dallmeier and Comiskey 1998). The abundance and distribution of several animals in the riverine floodplain can be keystone or indicator species that reflect the overall health of this ecosystem. These species include the some of the rare, endangered, or threatened fishes, amphibians, reptiles, birds, and mammals.

For this restoration plan, the frequency and magnitude of inundation of the riverine floodplain was determined for each alternative scenario and used to evaluate potential affects on vegetation and wildlife. Sufficient literature and historical Loxahatchee riverine floodplain vegetation information was available to quantify the relationship of long-term hydroperiods with the health of vegetation communities. However, there is limited information on wildlife within the floodplain that can be used for this type of analysis. Therefore, the following wildlife monitoring programs are recommended by FPS) at JDSP to provide baseline information for evaluations to guide future water management methods.

Amphibians

Amphibians can be used as indicators of the overall health of the floodplain ecosystem. They provide food for invertebrates, fish, reptiles, birds, and small mammals. However, no data are available on how saltwater intrusion and levels of inundation have impacted amphibian populations and production which changes from year to year in rainfall driven systems (Semlitsch et al. 1996). Different species of Florida amphibians require varying lengths of inundation for their larvae to metamorphose (SWFWMD 2002; see **Table 10-2**). As the length of the inundation period increases, so does larvae competition for resources, and predation (Semlitsch et al. 1996).

Recommendation – The monitoring of adult and metamorphic amphibian populations in the floodplain is recommended. The baseline monitoring should be defined in the NWFSP.

Table 10-2. Days of Inundation Required for Different Species of Native Frogs Found in Jonathan Dickinson State Park (JDSP) to Complete Metamorphosis (adapted from SWFWMD 2002).

Species	Days of inundation
Pig frog	360
Southern leopard frog	90
Green tree frog	60
Florida cricket frog	45-90
Southern toad	30-60
Squirrel / pinewoods tree frog	30-60
Eastern narrowmouth toad	30
Little grass frog	10
Eastern spadefoot toad	10

Bird Monitoring

A variety of birds use the floodplain of the NWFLR, including song birds, owls, raptors, and wading birds. The majority of listed bird species on the NWFLR are wading birds (**Table 10-3).** However, improved hydrology will potentially increase food resource availability such as invertebrates, amphibians, and fish and improve nesting habitat suitability for wading birds (Bancroft et al. 1988). Therefore, a monitoring protocol that will encompass the largest variety of birds is desirable.

Recommendation – The monitoring of bird populations in the riverine floodplain is necessary to establish baseline studies and to evaluate the effects of restorative flows on habitat and associated wildlife.. The baseline monitoring should be defined in the NWFSP.

Table 10-3. Threatened, Rare or Endangered Birds in the Northwest Fork of the Loxahatchee River.

Bird Species	FFWCC	USFWS	FNAI
Little Blue Heron	Species of Special Concern	None	G5 / S4
Tricolored Heron	Species of Special Concern	None	G5 / S4
Roseate Spoonbill	Species of Special Concern	None	G5 / S2
Snowy Egret	Species of Special Concern	None	G5 / S3
Wood Stork	Endangered	Endangered	G4 / S2
White Ibis	Species of Special Concern	None	G5 / S4
Limpkin	Species of Special Concern	None	G5 / S3
Bald Eagle	Threatened	Threatened	G4 / S3

Florida Natural Areas Inventory (FNAI) ranks legend:
G - Global occurrences.
S - State occurrences.
1. Critically imperiled, or less than six occurrences.
2. Imperiled or six to 20 occurrences.
3. Rare, restricted, or otherwise vulnerable to extinction.
4. Apparently secure.
5. Demonstrably secure.

Small Mammals

Small mammals affect the structure, composition and dynamics of natural communities through activities such as seed dispersal (Brewer and Rejmanek 1999), pollination (Janson et al. 1981; Fleming and Sosa 1994; Carthew and Goldingay 1997), mycorrhizal dispersal (Janos et al. 1995), impacts on insect populations (Yahner and Smith 1991; Cook et al. 1995) and as food for carnivorous animals (Greene 1988; Wright et al. 1994). Most small mammals like mice, moles, and rats as well as mid-size mammals including raccoons, Virginia opossum, and weasels, are not abundant in seasonally flooded cypress swamps (Harris and Vickers 1984). However, the presence and abundance of small mammals have been identified as potential indicators because of their ecological importance and link to specific ecological conditions.

Recommendation – The monitoring of small and mid-size mammals in the floodplain is recommended. The baseline monitoring should be defined in the NWFSP.

Fishes

Freshwater fish have a long history of being used to assess the ecological health of aquatic ecosystems (Karr 1981, 1991). Fish integrate ecological conditions over biologically relevant spatial and temporal scales, and can be effectively used to assess ecological conditions following river restoration efforts (Trexler 1995; Toth et al. 1998). Restoration activities will directly influence the timing and magnitude of water delivery to the main channel and flood plain of the Northwest Fork. This is expected to influence assemblage structure and tropic dynamics of constituent freshwater fish.

Recommendation – The monitoring of fish in the main channel and floodplain is recommended. The baseline monitoring should be defined in the NWFSP.

RIVERINE FLOODPLAIN VEGETATION MONITORING

The riverine floodplain in the Northwest Fork lies between Riverbend Park (RM 15.5) and Trapper Nelson's (RM 10.2) and is dominated by several communities of freshwater vegetation. The preferred flows in this restoration plan simulate the dry (spring) and wet (fall) seasons which provide the appropriate length of inundation and soil moisture needed for the two indicator communities (flood plain swamp and hydric hammock). Transect 1 (RM 14.5), Transect 2 (RM 13.43), Transect 3 (RM 12.07) and Transect 4 (RM 11.18) are located in the floodplain and have been extensively studied. These four transects, and two others, were originally characterized for vegetation in 1983 and 1984 by the SFWMD (Worth, 1984). Subsequently, additional transect data were collected (Ward and Roberts, 1993-1994), and most recently a joint FDEP/SFWMD study (Roberts and Hedgepeth) was conducted in 2003.

Recommendations – Continued monitoring of the riverine floodplain vegetative transects is necessary to identify changes in vegetative community composition and plant species distribution. Shrub and groundcover species should be relatively sensitive to improved hydrology thus, these shrub and groundcover changes should manifest within two to three years. Shrub and groundcover vegetation should be monitored at least every three years. Canopy species are longer lived and slower to respond; therefore, canopy species along transects should be examined every 6 years to assess community health and composition. Routine monitoring at Transect 1 and Transect 3 is necessary. Transect 1 is located just downstream of Lainhart Dam and is an indicator of health of the upper reaches of the freshwater riverine floodplain area. It is not tidally influenced so stage is directly correlated with flows over Lainhart Dam. There are no issues of salinity intrusion in the water column or soils. It is considered to be a reasonably healthy ecological area given a Wetlands Evaluation Summary (WRAP) score of 0.81 (out of a maximum of 1.0) in summer of 2004 by a team of wetland experts. The unique location of this transect along with groundwater monitoring, easy access for data collection, and a healthy WRAP score, support the use of this transect for long term monitoring activities. Transect 3 is downstream of Masten Dam. Like Transect 1, flows over Lainhart Dam influence water stages at this transect. Although stage at this site can be tidally influenced, there is no evidence of impact from saltwater intrusion this far upstream. This site has similar vegetation and ecosystem quality to the other transects downstream from Masten Dam yet it is far enough downstream from Masten Dam that it is not subject to the rapid water stage changes evident near Masten Dam. As an intermediate location between Transect 2 and Transect 4, it is an appropriate site for long-term monitoring for this portion of the floodplain. Data should be collected on a routine basis from Transect 2 and Transect 4 to provide a complete set of data.

TIDAL FLOODPLAIN VEGETATION MONITORING

The tidal floodplain is identified as the section of the Northwest Fork floodplain that lies between Trapper Nelson's (RM 10.2) at the upstream end and RM 4.5 at the downstream terminus. This section presently contains primarily brackish water vegetation. It has two segments including the "upper tidal" between RM 10.20 and RM 8.02, and the "lower tidal" occurring between RM 8.02 and RM 4.50. Three transects, Transect 6 (RM 8.43), Transect 7 (RM 9.10) and Transect 9 (RM 6.46), are located in tidal floodplain. River water levels in the tidal floodplain are influenced mostly by tides, however water levels can also be affected by flows from Lainhart Dam, Cypress Creek, Hobe Grove Ditch and Kitching Creek. Historical vegetation information is available for Transects 6 and 9 (Worth 1984; Ward and Roberts 1994; and Roberts and Hedgepeth 2003). Transect 7 and Transect 9 are the most appropriate locations to conduct routine monitoring for evaluation of biological constituents. Transect 7 has four groundwater and soil moisture monitoring stations across from the eastern end of Hobe Grove Ditch. It is an area of vegetative transition from freshwater to brackish water communities resulting from saltwater intrusion, changes in elevation, and historical logging. Transect 9 is on a peninsula adjacent to Jonathan Dickinson State Park boat ramp with three groundwater monitoring wells. This area, studied by Taylor Alexander from 1967 through 1971 and reexamined in 2003 (Roberts and Hedgepeth, has experienced losses of bald cypress and cabbage palms and is now primarily red and white mangroves. Ongoing studies indicate some of the highest salinity and sulfide levels in the Northwest Fork exist on this transect due to the lack of water exchange and flushing within the interior of the peninsular.

Recommendation – Monitoring the tidal floodplain transects is necessary to determine changes in species compositions and distributions. This area will experience an appreciable reduction in salinities from restoration flows and therefore a noticeable response in vegetation is expected. It is recommended that shrub and groundcover species be examined every three years and canopy species every six years.

ESTUARINE ECOSYSTEM MONITORING

OLIGOHALINE (LOW SALINITY ZONE) ECOZONE: FISH MONITORING

Environmental requirements of fish larvae in the Northwest Fork Low Salinity Zone (LSZ, RM 6.0 to RM 10.2) were used to determine potential affects of restoration flow alternatives. A hydrodynamic phenomenon that frequently occurs in the LSZ (0 ppt to 10 ppt) of many estuarine systems concentrates suspended materials and zooplankton, including fish larvae, causing a turbidity maximum. Fish larvae within the turbidity maximum have an increased probability of survival due to the presence of abundant prey and limited predation during a critical portion of their life history. Recent zooplankton sampling in the Northwest Fork reveals the greatest concentration of zooplankton occurred during the dry season (spring), upstream of RM 6.0 within a salinity range of 2 pt to 8 ppt. The Preferred Restoration Flow Scenario moved the LSZ and associated habitat of fish larvae downstream during the dry season (spring) with minimal impact on this resource.

RECOVER (CERP 2004) intends to document the long-term affects of implementing improved water management capabilities in the Loxahatchee River Watershed on tidally influenced, juvenile and adult transient and resident species associated with various habitats. These habitats include various bottom types (i.e. mud, sand, oysters), herbaceous vegetation, and forested shoreline habitats. Additionally, a statement of work to monitor juvenile and adult fishes in the estuary is being developed and should be evaluated for its applicability to the NWFSP. The NWFSP will provide the bases for this evaluation.

Recommendation – To determine the effects of the restoration flows, flora (vegetative transects) and fauna (fish larvae, amphibians, and macroinvertebrates) and water quality parameters in this portion of the Loxahatchee River need to be monitored. The results and recommendations derived from the NWFSP should be coordinated with RECOVER efforts.

MESOHALINE ECOZONE: OYSTER MONITORING

The LRD, SFWMD and the Fish and Wildlife Research Institute (FWRI) are working cooperatively to assess the oyster resources in the Loxahatchee Estuary. To support the Monitoring and Assessment Program (MAP) component of RECOVER, a long-term oyster monitoring program is being developed by FWRI. A pilot study will determine final monitoring locations and methodologies. This effort will focus on four aspects of oyster ecology: (1) spatial and size distribution patterns of adults, (2) distribution and frequency patterns of the oyster diseases *Perkinsus marinus* (“dermo”) and *Haplosporidium nelsoni* (MSX), (3) reproduction and recruitment, and (4) juvenile oyster growth and survival. Maps of oyster beds, density and health will be produced at routine intervals.

Recommendation – To enhance the probability that appropriate oyster mapping and monitoring for this plan are conducted, the results and recommendations derived from the NWFSP should be coordinated with RECOVER efforts.

POLYHALINE ECOZONE: SEAGRASS MONITORING

The SFWMD monitored seagrasses at four locations within the Loxahatchee Estuary from February 1986 through March 1988 (**Figure 10-2**). This monitoring was part of an effort to determine the environmental changes that may occur with increased flows into the Northwest Fork.

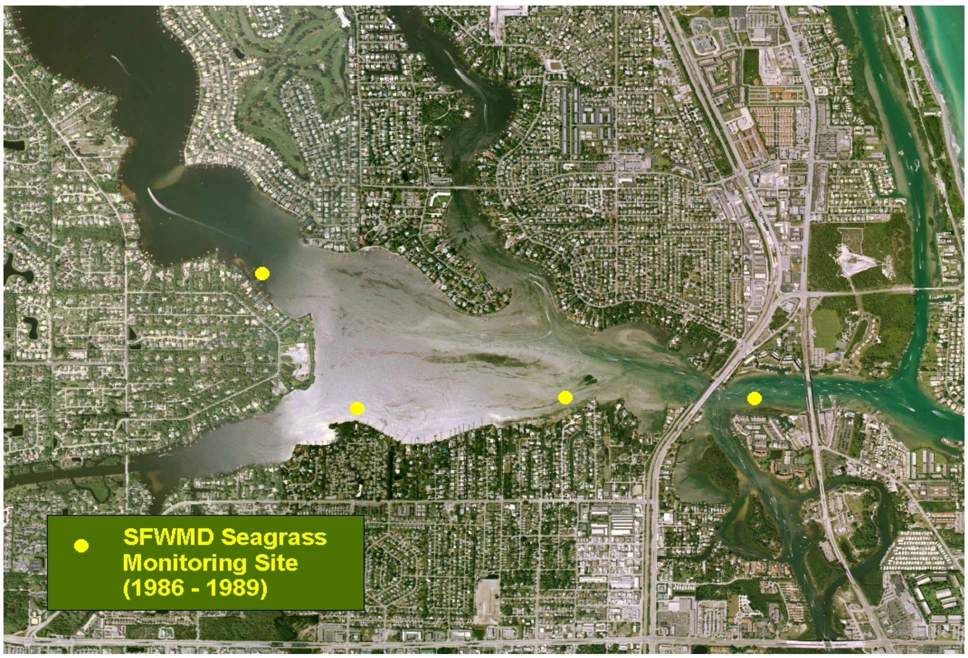

Figure 10-2. Locations of the Four South Florida Water Management District Historic Seagrass Monitoring Sites.

The LRD and SFWMD began a monthly seagrass monitoring program in the summer of 2003 (see **Chapter 4**, **Figure 4-9**) to determine seasonal variability of seagrass and macro algae and response of seagrass to freshwater flows (see details in **Chapter 4**). This seagrass monitoring is being conducted by LRD through summer of 2006. At that time, monitoring results will be evaluated to determine if any changes are needed in the monitoring program design.

Recommendation – Monitoring seagrass density, diversity, and coverage in relation to environmental parameters will document affects of restoration efforts and may provide information for a seagrass model**.** It is recommended that the results from the LRD study be implemented and an evaluation of baseline seagrass observations made in the 1980s be conducted for comparison with current observations.

Seagrass Mapping

Past and present seagrass mapping efforts are detailed in **Chapter 4**. These maps provide an understanding of large-scale seagrass distribution changes throughout the Loxahatchee River Estuary from the early 1980s to present. Methods currently being used include mapping seagrass signatures through the interpretation of true color aerial photography, groundtruthing, and an analytical stereoplotter.

Seagrass mapping is being conducted by the LRD which is funded by CERP (RECOVER 2004). In 2003/2004 the LRD produced a species-specific seagrass map using detailed groundtruthing and sub-meter accuracy GPS technology that was extremely useful as baseline information. Currently, all seagrass mapping and monitoring in CERP are being evaluated to determine if changes should be made to these monitoring programs.

Recommendations – Future seagrass mapping efforts are necessary to document and understand the environmental conditions that cause variability of seagrass species distribution and should include the following recommendations:

(1) Future seagrass mapping should cover the area from the Jupiter Inlet (RM 0.0) to RM 4.0 to capture all seagrass habitats in the estuary,

(2) Presently, IRL seagrass beds are mapped by the SJRWMD and SFWMD every two to three years from aerial photographs. This effort should be continued. However, these efforts do not map species distribution that could reveal important subtle affects of flow regime changes. This information is needed and should be determined in concert with ongoing mapping. New technologies that aerially differentiate seagrass species should be explored and implemented to reduce cost of species-specific mapping.

(3) To enhance the probability that appropriate seagrass mapping and monitoring for this plan are conducted, the results and recommendations derived from the NWFSP should be coordinated with RECOVER efforts.

BENTHIC MACROINVERTEBRATE MONITORING

The SFWMD collected benthic macroinvertebrate samples every other month at five locations from February 1986 through March 1988 (**Figure 10-3**).

Figure 10-3. South Florida Water Management District (SFWMD) Benthic Macroinvertebrate Monitoring Sites (1986 – 1988).

The LRD collected a set of benthic macroinvertebrate samples in the dry season (February) and the wet season (October) from 1992 to 1999 at nine stations in the watershed (see **Chapter 2**, **Figure 2-6**). Two additional stations (B69 and B67) were monitored from 1999 to present. During the 2004 monitoring period, two hurricanes occurred (Frances and Jeanne) providing valuable information on the response of macroinvertebrates to storm events. Species composition has been determined for most of the LRD samples and for all of the SFWMD samples. These data are being evaluated to determine trends and the identification of macroinvertebrate polyhaline indicator species.

Recommendation – Results of the macroinvertebrate evaluation should be used to develop a monitoring program that satisfies the requirements of the NWFSP.

SYNOPSIS OF EXISTING MONITORING PROGRAMS

Table 10-4 summarizes information concerning existing monitoring programs. All of the data collection methods and sampling frequency of these programs will be reviewed in light of the information needed and justified in the Northwest Fork Science Plan (NWFSP).

Table 10-4. Summary of Existing Monitoring Programs and Sampling Frequencies for the Northwest Fork of the Loxahatchee River.

Parameter	Monitoring Frequency						Responsible Agency
	Continuous	Monthly	Quarterly	Annually	3 Yrs	6 Yrs	
Systemwide Components							
Watershed Rainfall	X						SFWMD/LRD
Rainfall on floodplain	X						SFWMD/LRD
Water Quality parameters		X					LRD/SFWMD
Groundwater stage of floodplain	X						SFWMD/JDSP
Flow and stage over Lainhart Dam	X						SFWMD/USGS
Flow from other tributaries	X						SFWMD
Tide and Salinity	X						USGS/LRD/ SFWMD
Floodplain Ecosystems							
Fauna: amphibians					X		JDSP
Fauna: birds					X		JDSP
Fauna: mammals					X		JDSP
Fauna: Fish					X		JDSP/SFWMD
Vegetation: groundcover					X		JDSP/SFWMD
Vegetation: canopy						X	JDSP/SFWMD
WRAP evaluation						X	JDSP/SFWMD
Estuarine Ecosystems							
Oligohaline: fish larvae				X			SFWMD
Mesohaline: oysters				X			SFWMD/LRD
Polyhaline: seagrasses				X			LRD/SFWMD
Macroinvertebrates			X				JDSP/LRD/ SFWMD

SPECIAL STUDIES

Special studies are designed to answer specific questions identified in the Northwest Fork Science Plan (NWFSP) in a short time to assist in initial adaptive management efforts or to reduce uncertainties associated with plan development.

LOXAHATCHEE RIVER WATERSHED AND ESTUARINE MODELING

A key factor in the restoration of freshwater vegetation habitats is the affect of restoration flows on soil salinity and hydroperiod in the floodplain. To predict these affects, a model needs to be developed that integrates floodplain flows with surface water and groundwater exchanges. Supported by the FDEP and SFWMD, a model is being developed by the University of Central

Florida (UCF). This new model will integrate the existing estuarine surface water model to simulate surface and groundwater movement, stage and quality in the river and floodplain.

Monitoring programs recommended in this chapter will provide data needed to calibrate the integrated model. The close coordination between modeling teams and the continued support from the SFWMD and FDEP is paramount to completing this extremely important water management tool.

As more water quality data become available, water quality models will need to be developed for the Loxahatchee River Watershed and Estuary. These models will become essential tools to evaluate change in flows and nutrient loading on the water quality status in the Northwest Fork.

JONATHAN DICKINSON STATE PARK VEGETATION DEMONSTRATION PROJECT

This study by FPS at JDSP will evaluate the success of restoration and growth of desirable native vegetative species in areas aggressively managed for exotics removal. Exotic removal was conducted in the designated locations in April/May 2003 near RM 8.6. The target area success criteria is to achieve 80% success in survival of planted species and 80% coverage of desirable obligate and facultative wetland species after five years. The evaluation effort is ongoing and is expected to be completed in 2007.

VEGETATION RESPONSE TO SEVERE STORMS OR DROUGHTS

The high winds and flooding in the Northwest Fork floodplain from two hurricanes in 2004 (Frances and Jeanne) destroyed canopy trees, understory vegetation and ground cover. Routine assessments of the impacted vegetative communities by FPS at JDSP will help document system response and recovery from these types of extreme weather events.

SOIL STUDIES

The SFWMD has supported the University of Florida (UF), Tropical Research and Education Center to determine relationships among floodplain vegetation, surface water and groundwater stage and salinity as well as soils. Additionally, the rate of soil moisture change at depth after inundation of the floodplain will be ascertained. Soil salinity from the surface 20 cm at 10 vegetation transects is being evaluated. Soil cores from each vegetation transect are also being used in laboratory studies to determine salinity movement during controlled rainfall conditions.

CYPRESS SEEDLING STUDIES

This study is designed to determine how cypress seedlings are affected by salt water and is being conducted by UF. Because salinity levels in the riverine floodplain will decrease when restoration flows are implemented, the salt tolerance of bald cypress seedlings is an important aspect of restoration. The study will be completed in 2008.

SYSTEM RESPONSE TO RAINFALL EVENTS AND DROUGHTS

Special studies are necessary to document short term changes of water quantity and quality of watershed runoff from various rainfall events. This information, collected concurrently with estuarine water quality, will provide data needed to calibrate an estuarine water quality model used to develop Pollution Load Reduction Goals (PLRGs) and Total Maximum Daily Loads (TMDLs).

MESOCOSM STUDIES

This plan has demonstrated the importance of understanding salinity tolerances of seagrass species to evaluate the potential impacts of alternative inflow regimes. A recent, extensive literature search provided sufficient seagrass salinity tolerance information for several species to conduct this evaluation, however, it has also revealed a paucity of information on several important species such as Johnson's seagrass and manatee grass. Controlled laboratory studies need to be conducted to determine the response of these species to various salinity regimes. With this additional information available, the existing monitoring and mapping efforts in concert with salinity tolerances of these species will reveal the level of detailed data needed to better evaluate restoration flow scenarios.

OYSTERS

The distribution and abundance of oysters in relation to salinity has been determined for the Northwest Fork. The oyster model predicts the preferred restoration flow alternative will move the suitable salinity environment downstream with minimum impact on the majority of oyster beds. However, mitigation for the oyster beds lost upstream from RM 4.0 can be addressed by providing substrate (cultch) in the area near RM 4.0. An investigation needs to be undertaken to determine locations and sizes of oyster beds that can be created. Once implemented, the success of this oyster bed creation project should be documented.

FISH LARVAE

The preferred restoration flow scenario augments dry season flows in a pulsing fashion that simulates the hydrograph of a small rainstorm event to benefit estuarine fish larvae. This is one of the most important and frequently used water management techniques recommended in this plan. However, an appropriate, environmentally sensitive way to implement this concept has not been determined. A special study to document the riverine floodplain response to short-term changes in water levels and the impact on fish larvae dynamics within the LSZ during the dry season should be conducted during controlled pulse releases from Lainhart Dam.

CONCLUSIONS

Ecological monitoring is essential to evaluate the effects of quantity, quality, timing and distribution of increased dry season flows and improved wet season flows in the Northwest Fork of the Loxahatchee River. As flows change over time, the response of the biological communities must be also measured. Along with these long-term monitoring activities, special studies will also be identified to address specific issues associated with the Restoration Plan. The information obtained shall be used to support adaptive management processes by modifying water resources operation protocols. The Northwest Fork Science Plan will provide a framework to integrate information derived from on-going studies and needed future efforts to enhance the evolution of the adaptive water management process. The status of this process will be reported to the public every five years. As more information is obtained, 5-year updates to the Restoration Plan will also be necessary.

CHAPTER 11

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Chapter 11

Implementation of the Restoration Plan

INTRODUCTION

The need for restoration flows to the Northwest Fork has been recognized for many years. In the mid-1980s the USGS calculated restoration flows to be 50 cfs. This rate was established as the official operation and management flow target and has been used by the SFWMD since that time. The results from detailed studies of the Loxahatchee River Watershed, which began in the mid-1990s, led to the development of analytic tools that made modeling of the system possible. In the mid-1990s, a multi-agency team of resource managers estimated that a dry season flow of approximately 65 cfs, over the Lainhart Dam, to the Northwest Fork was necessary to protect resources from the effects of upstream incursion of salt water. This flow was used as the target for the Northern Palm Beach County Comprehensive Water Resources Management Plan (NPBCWMP; SFWMD 2002b). In 2002, a “minimum flow” of 35 cfs across Lainhart Dam was identified by the SFWMD as the amount of water needed to protect the remaining freshwater floodplain vegetation along the Northwest Fork from significant harm caused by saltwater intrusion (SFWMD 2002a).

In 2003, work began by FDEP and SFWMD, along with the Loxahatchee River District (LRD), on the development of a “practical restoration plan and goal” for the Northwest Fork of the Loxahatchee River. Best available data, additional field studies and current models were used to evaluate a series of flow scenarios and their effects on the freshwater, tidal and estuarine reaches of the river system as described in this report. A flow target (goal) for the Northwest Fork of the Loxahatchee River is established with the intent to protect the existing freshwater riverine floodplain, restore a remaining portion of the river’s historic cypress floodplain forest, protect this resource from damage due to saltwater intrusion, re-establish freshwater vegetation in areas of the floodplain that have been impacted by saltwater intrusion, protect fish larvae habitat, and protect oysters and seagrasses in the estuarine reach of the Northwest Fork. Careful monitoring of the system will be required to evaluate the long-term effects of proposed changes in water levels, hydroperiods and flows on plant and animal communities that currently occupy the river floodplain. Flow adjustments may be necessary as more knowledge and experience is gained regarding these important resources.

The means for achieving the proposed flow targets are under development. Many individual projects and facilities and improved operations will be required during the coming decades to achieve the restorative flows and ensure that the resources of the Northwest Fork reach their intended long-term goals. The primary mechanisms that will be used to plan and construct facilities needed to provide this additional water are the North Palm Beach County Project, Part 1 and Part 2 components, of the Comprehensive Everglades Restoration Plan (CERP NPBC, Part 1 and Part 2). However, additional support from many other activities and entities will be required to provide supplemental infrastructure, protect the ecosystem and to operate, manage and monitor this system.

CERP NORTH PALM BEACH COUNTY PROJECT

The targets identified in this document address the quantity, timing and, distribution of water deliveries needed for the protection and restoration of the Northwest Fork of the Loxahatchee River, based on the best available information and up to date models. The next step in the process will be conducted under the auspices of the Comprehensive Everglades Restoration Plan (CERP), North Palm Beach County (NPBC) Project, Part 1 and Part 2. To prevent delay to the projects, the CERP NPBC Project Implementation Report (PIR) was divided into two parts. Part 1 contains all the project features that do not involve ASR systems and Part 2 contains ASR system projects. Using the flow targets established in this plan for the Northwest Fork, the NPBC Project will evaluate various alternative methods for meeting these future water needs. When the analyses are completed by the USACE and the SFWMD, the infrastructure projects, operational protocols and regulations needed to meet these requirements will be identified.

CERP NORTH PALM BEACH COUNTY PROJECT – PART 1

The CERP North Palm Beach County Project, Part 1 (CERP NPBC-Part 1) is a CERP component and includes elements or projects that were identified in the Northern Palm Beach County Comprehensive Water Management Plan (Northern Plan). The CERP NPBC-Part 1 was expanded with additional elements that were included because of the larger regional scope and the 50-year design horizon of CERP. One of the goals of CERP NPBC-Part 1 is to provide 48,000 acre/feet of storage in the L-8 Basin reservoir. Storage in the L-8 Basin reservoir will increase dry season water availability for improved hydroperiods for the Loxahatchee Slough and restorative flows to the Northwest Fork of the Loxahatchee River. Another goal is to design and construct the facilities needed to reconnect and manage the water flows and levels within the Grassy Waters Preserve and Loxahatchee Slough, which were severed by the construction of various canals, roads and railways in the project area. In addition, wet season stormwater discharges to the Lake Worth Lagoon will be attenuated and drainage improvements will be provided for Indian Trail Improvement District.

The SFWMD recognized that many of the elements within the CERP NPBC-Part 1 Project are essential to deliver necessary dry season restorative flows to the Northwest Fork. Therefore, in parallel with the USACE CERP planning process, the SFWMD moved ahead with the design and construction of the G-160 - Loxahatchee Slough Structure, and the G-161 – Northlake Boulevard Structure, along with the acquisition of 47,000 ac/ft of storage in the L-8 Reservoir and preparations are taking place to start construction of the G-161, Northlake Blvd. structure. Other related improvements such as the widening of the M-Canal, and the relocation and expansion of the Control #2 (Loxahatchee) Pump Station, will also take place on this expedited path in partnership with the City of West Palm Beach. The SFWMD will coordinate with the USACE during the planning process to ensure the work performed by the SFWMD is included in the alternatives analysis and incorporated where appropriate in the selected plan, which will be documented in the Project Implementation Report (PIR). The contributions and significance of these components was clearly identified in the Northern Plan. It is anticipated that if these components continue to demonstrate their worth through the analysis of the PIR effort that they will be included in the recommendation to Congress for cost sharing consideration.

The Restoration Goal and Plan for the Northwest Fork have identified the amount, timing and distribution of restoration flows to be delivered by the CERP NPBC-Part 1 Project elements. The restoration flow target is being incorporated into the CERP NPBC-Part 1 modeling effort, which will evaluate the alternatives for water delivery to the Northwest Fork. The PIR currently being developed will identify the means and methods necessary to meet these future requirements. This effort is underway by the SFWMD and the USACE and supported by other agencies, local governments, public and private entities.

CERP NORTH PALM BEACH COUNTY PROJECT – PART 2

The CERP North Palm Beach County Project – Part 2 (CERP NPBC-Part2) includes two separable elements: the C-51 Regional Groundwater ASR system and L-8 Basin ASR system. These projects will provide additional long-term storage within the NPBC region.

The C-51 Regional Groundwater ASR System project includes a series of ASR wells with a total capacity of 170 million gallons per day and associated pre- and post- water quality treatment to be constructed along the C-51 Canal and canals that can receive water from the C-51 Canal. The conceptual design assumes 34 well clusters, each with an individual capacity of 5 million gallons per day fed by a combination of vertical and horizontal wells located near existing canals. The conceptual design includes disinfections pre-treatment and post-storage aeration. The level and extent of treatment and number of the ASR wells may be modified based on findings from a proposed ASR pilot project. The purpose of this project is to capture and store excess flows from the C-51 Canal, currently discharged to the Lake Worth Lagoon, for later use during dry periods.

The L-8 Basin ASR System project includes ASR wells with a total capacity of 50 million gallons per day and associated pre- and post-water quality treatment to be constructed in combination with the L-8 Reservoir. The conceptual design consists of 10 wells, each with an individual capacity of 5 million gallons per day for a total capacity of 50 million gallons per day. The conceptual design includes disinfection pre-treatment and post-storage aeration. The level and extent of treatment and number of the ASR wells may be modified based on findings from a proposed ASR pilot project.

The purpose of these projects is to increase water supply availability, maintain or enhance flood protection for northern Palm Beach County areas, and moderate water level within the West Palm Beach Water Catchment Area. It will also provide flows to enhance hydroperiods in the Loxahatchee Slough, increase base flows to the Northwest Fork of the Loxahatchee River, and reduces high discharges to the Lake Worth Lagoon. During periods when the West Palm Beach Water Catchment Area is above desirable stages, 50 million gallons per day will be diverted for storage in the ASR wells.

Flows to the Northwest Fork over Lainhart Dam

The next steps in the process are for the CERP NPBC Projects to: a) study the feasibility of the proposed flow targets, b) estimate the amount of supplemental water required to be delivered to the NW Fork and the tributaries, c) determine amount and location of storage facilities needed within the basin and d) identify ongoing or proposed projects or combinations of projects that can meet these needs. Projects that were initially identified as part of the Northern Plan (SFWMD 2002b) provide a starting point. Previous studies (SFWMD 2002a) indicated that these projects, when completed could provide a sustained dry-season flow of 65 cfs or more over the Lainhart Dam to the Northwest Fork of the Loxahatchee River approximately 94% of the time. The restoration target presented in this report requires flow in the range of 65-90 cfs over the Lainhart Dam during the dry season; therefore, some additional water supply sources may be required.

Tributary Flows to the Northwest Fork

Analyses are also needed to estimate water deliveries from the tributary systems of the Northwest Fork that are downstream of the Lainhart Dam. The analysis and data represented in this document have outlined some general tributary flow targets from Cypress Creek (RM 10.33), Hobe Grove Ditch (RM 9.07) and Kitching Creek (RM 8.13). It is anticipated that the restorative flows will reduce the migration of salt water without damaging the pristine floodplain wetlands in the upstream"Wild and Scenic" reaches of the Northwest Fork. In addition the preferred restoration flow scenario will not adversely impact the juvenile fish nurseries and the oysters or seagrasses in the estuarine reach of the Northwest Fork system. A combined dry season flow of approximately 30 cfs from the three main tributaries has been identified as a current flow. 60 cfs of combined flow has been estimated to be the target for the three downstream tributaries.

The planning process of CERP NPBC projects will further refine the flows from the tributaries downstream of the Lainhart Dam. This will include the quantities of water needed at different times of the year, the source(s) of additional flow volumes, and how these flows should be distributed among the tributary basins. As part of the CERP process, various water management options and combinations of options will be developed to determine the best solution. A more detailed project design for the selected alternative will be developed that includes estimates of project costs and project timeframes to provide supplemental flows.

REGULATORY IMPLEMENTATION

Regulatory impacts of the proposed flow targets are necessary to be defined and stated. The proposed flow targets may have implications on Consumptive Use Permitting within the watershed. The restoration flow targets for the Northwest Fork of the Loxahatchee River essentially provide a foundation for the determination of an additional demand on any "new" water captured or developed within the watershed. Any new facilities that provide additional water will need to be evaluated to determine how much of the additional water is needed to meet environmental resource protection criteria and how much may be available for allocation for consumptive uses. The SFWMD has various tools that can be used to protect natural water bodies from the effects of surface or ground water withdrawals.

MINIMUM FLOWS AND LEVELS RULE

The SFWMD MFL rule (CH 40E-8 F.A.C.) for the Northwest Fork of the Loxahatchee River, adopted in 2003, identified a minimum flow of 35 cfs and developed a recovery plan that includes projects, regulatory tools and operational modifications to the river and watershed that will, over time, achieve a sustained flow of 65 cfs to the Northwest Fork, approximately 94% of the time. The SFWMD is presently in the process of developing additional minimum flow criteria for the major tributaries, including Loxahatchee Slough, Cypress Creek, Hobe Grove Ditch and Kitching Creek. This effort is scheduled to be completed in 2007.

INITIAL WATER RESERVATIONS

The Florida legislature has defined water reservations as one of several tools that can be used by water management districts to protect water resources potentially threatened by water supply development activities. Section 373.223(4) Florida Statues provides the basis for establishing reservations as a means to protect fish and wildlife resources. The purpose of the initial reservation is to quantify the amount of existing water that is needed to protect fish and wildlife resources within the river and protect it from future consumptive uses. Water reserved under this statute is not available for allocation for consumptive uses. All presently existing legal uses of water will be protected so long as such use is not contrary to the public interest. Fish and wildlife resources are considered to be protected based on a suite of science-based environmental performance measures and targets that if met, will maintain healthy lake, wetland, riverine and/or estuarine communities. In March 2005, the SFWMD Governing Board approved staff's proposed rule development schedule for establishment of an *initial water reservation* for the Northwest Fork of the Loxahatchee River.

An initial reservation addresses existing water resources that may be available for the protection of fish and wildlife resources. The District's approach for establishing the initial reservation for the Northwest Fork of the Loxahatchee River consists of the following key steps: a) define the area where the initial water reservation will be established, b) select the appropriate scale hydrologic model (i.e., regional or subregional) to perform the water quantification analyses, c) define environmental targets that equate to protection of fish and wildlife resources for the riverine floodplain and downstream estuary, d) define model assumptions in terms of existing conditions including protection of existing legal users, e) perform the model simulation and graphically display results in concert with the methods outlined in CERP Guidance Memorandum #4 (USACE 2005) to determine the quantity of existing water that is needed for protection of fish and wildlife, e) document all methods and results in a peer reviewed technical document, and f) based on the findings of the technical document, prepare draft rule language, conduct public rule development workshops and request Governing Board rule adoption.

If model results show that the amount of water that is currently being delivered to the river is needed for the protection of fish and wildlife, then that quantity of water shall be reserved from future consumptive use allocation. If the amount of existing water currently exceeds the amount needed for protection of fish and wildlife, then the additional water may be available for other uses. Initial reservations will be implemented through rule adoption and will ultimately be used as part of the District's consumptive use permitting and water shortage programs.

PROJECT WATER RESERVATIONS

The primary difference between an initial water reservation and a *project-specific water reservation* is that initial reservations are implemented under State law (Section 373.223(4) F.S.) and identify the amount of <u>*existing water*</u> that is needed for protection of fish and wildlife. In contrast, project reservations are largely a federal process based on the Water Resources Development Act (WRDA) 2000. These programmatic regulations are designed to quantity the amount of water that is <u>*captured or produced by a CERP or Acceler8 project*</u>, that can be delivered to a natural system, and that is needed for protection of fish and wildlife resources and other water related needs of the region. Guidance Memorandum #4 (USACE 2005) provides the methodology that will be used in the development of PIRs for identifying the appropriate quantity, timing and distribution of water dedicated and managed for the natural system and other water-related needs of the region.

If the analysis conducted for development of initial water reservations indicates that the amount of water currently delivered is less than the amount needed for protection of fish and wildlife, then an additional project-specific water reservation will be developed for any new regional water management facility that is constructed in the future in the Loxahatchee River watershed. Each project will include a design specification that identifies the amount of "new" water that will be captured or produced by the project. Based on this amount, some portion of this water may be "reserved" by the SFWMD Governing Board, to the extent that it contributes toward achieving the total amount of water needed to protect fish and wildlife. The SFWMD Governing Board may determine that the project also provides additional water, beyond the amount needed for protection of fish and wildlife resources, which can then be allocated to other water-related purposes, including consumptive uses.

OPERATIONAL PROTOCOLS

The restorative flows presented in this document provide the foundation for and include a preliminary attempt to determine the operational feasibility of a proposed flow regime. The intent of such an analysis is to provide the SFWMD Operations Department with a procedure that can be used to regulate water deliveries from the C-18 Canal through the G-92 Structure, on a seasonal basis and in a manner that will provide the prescribed stages and flows in the downstream river floodplain. These operational protocols need to be translated into gate openings that are adjusted periodically, depending on the relative upstream and downstream water levels, and flows across Lainhart Dam. Management of water levels upstream of G-92 (Loxahatchee Slough) will also be needed, to ensure that sufficient water is available for dry season deliveries. This will require consideration of water deliveries through the South Indian River Water Control District structures and the G-160, Loxahatchee Slough Structure, as well as consideration of water elevations in the C-18 Canal. Operation protocols will be developed for the G-160-Loxahatchee Slough Structure, operation of adjacent culverts, the G-161-Northlake Boulevard Structure, the Grassy Waters Preserve/West Palm Beach Water Catchment Area, M-Canal, the C-2 (Loxahatchee) Pump Station, L-8 Canal and L-8 Reservoir, when all these projects are on line and fully functional.

The analysis conducted in this plan did not take water availability into consideration during the development of the restoration flow alternative for the Northwest Fork. The focus of the plan was to identify the flows necessary for the protection and restoration of the Northwest Fork and it was assumed that the additional water needed would be delivered through the G-92 structure from an undefined and unlimited upstream water source and from the tributaries downstream of the Lainhart Dam.

A more specific analysis of operational procedures will be required as part of the detailed design of the alternative plan selected by CERP NPBC-Part 1 and Part 2. An optimization analysis, similar to studies conducted in the Caloosahatchee and St. Lucie watersheds, may be needed to determine the ability of the overall system of structures, storage areas, and flowways to meet water needs of the Northwest Fork. Such an analysis may also be needed to demonstrate the feasibility and cost of the plan and may also identify opportunities to provide additional water through improved operations of existing facilities.

MONITORING AND AN ADAPTIVE MANAGEMENT APPROACH TO PLAN IMPLEMENTATION

The basis of the adaptive management approach to the implementation of this plan is described in **Chapter 10.** A Northwest Fork Science Plan (NWFSP) will be developed to identify the data needed to monitor and assess the riverine, tidal and estuarine reaches of the Northwest Fork. The NWFSP will outline specific activities required to measure water flows and evaluate long-term biological effects of the preferred restoration flow scenario. Upon adoption of the plan, a report will be compiled every five years that will identify observed changes and trends. The benefits of restorative flows to the system will be measured through monitoring. Data collection and analysis will ensure that adaptive management decisions will be scientifically based and documented.

The LRD has monitored water quality in the Loxahatchee River for several decades, gathering data on several parameters in addition to salinity. To avoid duplication the SFWMD has entered into a partnership agreement for cooperative efforts with the LRD in monitoring the water quality and seagrasses in the various reaches of the Northwest Fork, as well as the Central

Embayment and the Jupiter Inlet areas. These activities also will be incorporated into the science plan developed for the Northwest Fork.

Monitoring and assessment is a part of the NPBC CERP effort and implemented through, or in close coordination with, the CERP RECOVER program, which focuses on the estuarine resources of the Loxahatchee River. In addition, over the years SFWMD cost-share funds have supported USGS monitoring for the Loxahatchee River for salinity and other parameters.

ADDITIONAL IMPLEMENTATION ACTIVITIES

The following section identifies other State and Federal programs, agencies, local entities and public and private organizations that play an active role in carrying out the recommendations identified in this report. This restoration plan will be implemented through a variety of projects and plans, some of which are underway. Ultimately, the CERP NPBC Project will provide an analysis that shows incremental increases in water flow to the Northwest Fork over time as project facilities are constructed and become operational, associated construction costs to achieve the restorative flows, operation of various project facilities, and a list of other projects or activities that may provide additional water. This analysis will clearly show the linkage between the preferred restoration flow alternative and other ongoing and proposed activities by the SFWMD, CERP and the other partners identified below:

SFWMD ACTIVITIES

Northern Palm Beach County Comprehensive Water Management Plan

Initiated in 1995, the Northern Palm Beach County Comprehensive Water Management Plan (Northern Plan) was accepted by the SFWMD Governing Board in May 2002 (SFWMD 2002b). The sub-regional Northern Plan focuses on the southern L-8 Basin, the City of West Palm Beach Water Catchment Area (WCA-1) or Grassy Waters Preserve, C-18, the Loxahatchee Slough, and the Loxahatchee River, especially the Northwest Fork. The plan projects future water supplies for urban, agricultural and environmental uses for the year 2020.

The Northern Plan calls for a series of system improvements to be constructed in the area of Palm Beach County located north of Southern Boulevard and south of the Martin-Palm Beach County line, generally east of the L-8 Levee, and west of I-95. When all the proposed system improvements are in place, the Northern Plan will provide the projected 2020 public water supply demands of the area, hydrologic restoration of the Loxahatchee Slough, and protection of the Grassy Waters Preserve and a target base flow of approximately 65 cubic feet per second (cfs), in the dry season, measured at the Lainhart Dam, to the Northwest Fork of the Loxahatchee River. Construction has started on several of the Northern Plan components: the Loxahatchee Slough structure (G-160) was completed in January 2004; design of the Northlake Boulevard structure (G-161) was initiated in 2004 with construction started in 2005; and, the regional reservoir storage at the Palm Beach Aggregates site was increased through acquisition to 47,000 acre feet in 2004. The Northern Plan forms the basis for the North Palm Beach County CERP Project, Part 1, (CERP NPBC Part 1). It is being implemented through partnerships with the City of West Palm Beach, Indian Trail Improvement District, and Palm Beach County. State Legislative appropriations have been allocated for construction of system improvements.

Lower East Coast Regional Water Supply Plan

The SFWMD Governing Board adopted the *Lower East Coast Regional Water Supply Plan* (LEC Plan) in May 2000. The purpose of the LEC Plan is to fulfill the requirements of Section 373.0361, Florida Statutes (F.S.) for regional water supply plans. Implementation of the LEC Plan will do the following:

- Create a water supply that fully meets the future (2020) needs of almost seven million people, agriculture and industries during 1-in-10 year drought.
- Reduce the number of exceedances of Minimum Flows and Levels (MFL) criteria for the Everglades, Lake Okeechobee and the Biscayne Aquifer by 2020.
- Reserve from allocations sufficient water to allow for the restoration of the Everglades and enhancement of other significant South Florida natural systems.
- Reduce the uncertainty for issuing long-term permits for water users as they invest in tomorrow’s water supply infrastructure.
- Provide public forums to modernize District operational procedures and promote greater flexibility in the operation of the regional water management system.

Several LEC Plan recommendations also provide the foundation for various actions to protect and restore the Northwest Fork of the Loxahatchee River:

- LEC Recommendation 21: L-8 Project
- LEC Recommendation 32: Periodic Operational Flexibility
- LEC Recommendation 34: Water Reservations
- LEC Recommendation 35: Establish MFLs

Upper East Coast Water Supply Plan

The *Upper East Coast Water Supply Plan* (UEC Plan) was completed in 1998 and updated in 2004. Implementation of the UEC Plan will accomplish the following:

- Identification of eight water source options, which are aquifer storage and recovery, conservation, Floridan aquifer, reclaimed water, reservoirs, seawater, surface water and surficial aquifer.
- With appropriate management and diversification of water supply sources sufficient water to meet the needs of the region during a 1-in-10 year drought condition through 2025 will be available.

Several UEC Plan recommendations also provide the foundation for various actions to protect and restore the Northwest Fork of the Loxahatchee River:

- Recommendation 14: Continue implementation of the NPBCCWMP.
- Recommendation 15: Complete the CERP NPBC Project – Part 1 Project Implementation Report and implement the findings.
- Recommendation 16: Develop a restoration plan for the Loxahatchee River
- Recommendation 17: Establish an initial water reservation for the Northwest Fork of the Loxahatchee River.

- Recommendation 18: Review and revise the MFL and associated recovery strategy for the Northwest Fork of the Loxahatchee River by 2005.

- Recommendation 19: Establish MFLs for tributaries to the Northwest Fork of the Loxahatchee River

PARTNERS IN PLAN DEVELOPMENT AND IMPLEMENTATION

Florida Department of Environmental Protection, Florida Park Service, Jonathan Dickinson State Park

The Florida Park Service (FPS) and Jonathan Dickinson State Park (JDSP) staff worked closely with the SFWMD and the LRD to develop the preferred restoration flow scenario for the Northwest Fork. JDSP personnel contributed important field work, knowledge and biological experience important to the success of the plan. Jonathan Dickinson State Park was opened in 1950 and consists of approximately 11,383 acres in Martin County and northern Palm Beach County. The park occupies much of the watershed and most of the floodplain of the federally designated Wild and Scenic portion of the Northwest Fork of the Loxahatchee River. JDSP supports many unique natural features and significant cultural resources, including a 2,600 acre wilderness preserve and 2,100 acres of highly endangered scrub community. Twelve natural communities occur within the unit, including six wetland communities. These natural features create an exceptional environment for plants and wildlife including many designated rare, threatened and endangered species.

The park has a management plan (FDEP 2000) that serves as the basic statement of policy and direction for management of JDSP as a unit of Florida's State Park System. The plan consists of three interrelated components; resource management, land use and operations. Park goals and objectives include preserving the park's natural resources, creating awareness and appreciation for the park, enhancing organized programs and increasing attendance and visitation. The resource management component provides a detailed inventory and assessment of the natural and cultural resources, management problems and needs, specific management objectives, and guidance on the application of specific measures such as prescribed burning, exotic species removal, and restoration of natural conditions. The land use component provides a recreational resource allocation plan that is based on considerations such as access, population and adjacent land uses, allocation of physical space, location of use areas, estimated usage and types of facilities to be provided. The management plan provides an important tool to direct restoration and protection needs and management activities across a major portion of the Northwest Fork of the Loxahatchee River within JDSP and to some extent the watershed.

In addition, the Loxahatchee River Estuary and adjacent areas of the Intracoastal Waterway south of the Jupiter Inlet are designated by the state as an Aquatic Preserve. The Loxahatchee River – Lake Worth Creek Aquatic Preserve was adopted under Florida Statutes Section 258 by the State of Florida on November 2, 1970 and is managed by the FDEP, Office of Coastal and Aquatic Managed Areas (CAMA). Designation as an aquatic preserve provides a basis to support future management of this system in a natural state, including efforts to restore flows to the Northwest Fork and appropriate salinity regimes within the estuary. A management plan for this preserve was adopted in 1984. The aquatic preserves and JDSP are also identified by FDEP's Outstanding Florida Waters designation; hence these have the highest standards for protection of water quality within the river and estuary.

The collaboration and cooperation that was established through the development of the plan will extend in the future. Cooperative efforts include data collection, monitoring and analysis, evaluation of restorative flow effects and plan updates every five years.

LOXAHATCHEE RIVER WATERSHED ACTION PLAN

In July of 1996, the Florida Department of Environmental Protection, Southeast District Office organized the Loxahatchee River Watershed Planning Committee to develop a management plan for the Loxahatchee River Watershed. The goals and objectives were developed through public process that involved all stakeholders within the watershed, including local, state and federal agencies, environmental groups, businesses and private citizens. Environmental restoration projects, proposed and on-going, were identified by sub-basin and are listed and described in the action plan document. The Loxahatchee River Watershed Action Plan was published in October 2002.

Many of the projects identified in the Loxahatchee River Watershed Action Plan have been accomplished through ongoing commitments by local, regional, state and federal agencies. The projects have ranged from exotic vegetation removal by Palm Beach County in the Loxahatchee Slough to retrofitted urban stormwater systems in the Town of Jupiter. In addition, important tracts of land have been purchased within the watershed by Martin County, Palm Beach County, and SFWMD.

LOXAHATCHEE RIVER PRESERVATION INITIATIVE

The Loxahatchee River Preservation Initiative (LRPI) is one of the productive outcomes of the Loxahatchee River Watershed Action Plan effort spearheaded by FDEP in 1996. The LRPI was formed in 2000 with the single purpose of seeking appropriations from the state and federal governments for local projects that would improve and protect the natural resources within the Loxahatchee Watershed. Several key local projects, critical to preserving the long-term health of the Loxahatchee, have been implemented with LRPI funds, such as urban stormwater improvements and retrofits, exotic vegetation removal, and stormwater structure construction to upgrade water quantity and water quality discharges to the Loxahatchee. The state appropriations have provided incentives and maintained momentum to protect the Loxahatchee River through the funding of local projects. Eighteen projects are slated to be completed in 2006 with the support of $3.5M in LRPI funds.

Loxahatchee River District

For three decades, the Loxahatchee River District (LRD) has provided regional wastewater management for a 73 square mile area that includes Tequesta, Jupiter, Juno Beach and unincorporated areas of northern Palm Beach and southern Martin counties. The LRD is recognized for its excellence in operations by the State of Florida and declared "Best in Nation" by the Environmental Protection Agency. In addition, the LRD has been guided by its mission to preserve and protect the Loxahatchee River, Florida's only Wild & Scenic River through environmental management, river research, pollution control and environmental education. The LRD conducts research in the river and its watershed to focus on aquatic resources and water quality. Ongoing efforts monitor biological, chemical and physical trends in water quality, benthic invertebrates and seagrass communities in order to quickly identify and eliminate pollution sources and assess the general health of the river. In December 2004 the LRD and the SFWMD entered into a cooperative agreement to cost share on monitoring and to continue and enhance the established monitoring and data collection programs of the LRD. The LRD is a member of the LRMCC and has played an active role in the protection of the Loxahatchee River.

Loxahatchee River Management Coordinating Council

An outcome of the state and federal government actions to designate the Northwest Fork of the Loxahatchee River as a "Wild and Scenic River" was the formation of the Loxahatchee River Management Coordinating Council (LRMCC) through state legislation. Comprised of regional, state, federal agency and local government representatives, it oversees the impacts of proposed development, tracks plans and programs in areas adjacent to the Northwest Fork and its corridor, and is responsible for the development of a management plan for the river.

LOXAHATCHEE RIVER NATIONAL WILD AND SCENIC RIVER MANAGEMENT PLAN

Written by the FDEP and the SFWMD, and approved by the LRMCC, the SFWMD Governing Board and the Secretary of the FDEP, the *Loxahatchee National Wild and Scenic River Management Plan* (2000) ensures that special consideration be given to the watershed surrounding the river corridor so that it is protected to maintain natural flow conditions, good water quality and the preservation of high quality natural areas. The LRMCC oversees the update of plan every five years. The development of the plan update is shared by FDEP, FPS and the SFWMD to track the accomplishments of the member agencies and local governments and to identify new projects and programs, all of which are necessary for the protection and restoration of the Northwest Fork. The plan document was updated in 2000 and an updated plan document will be completed in 2006.

Martin County and Palm Beach County

These two county governments that comprise the Loxahatchee River watershed are important partners in efforts to effectively manage the Loxahatchee River. The counties own large tracts of land that are managed for protection and enhancement of natural resources and recreational uses. These entities also participate as partners with the SFWMD in regional land acquisition and management decisions. Counties and local governments also have primary authority for regulating land use decisions on privately-owned tracts within the watershed that are outside of municipal boundaries. Palm Beach County has played a significant role in the development and funding of Loxahatchee River related projects and has leadership responsibilities in the protection and maintenance of the Loxahatchee Slough, and Riverbend Park. Wetlands restoration in Riverbend Park may provide additional flows and water quality benefits to the Northwest Fork. Palm Beach County and Martin County have been an essential land acquisition partners with the SFWMD in accumulating land in Pal-Mar and other areas that will benefit the Northwest Fork of the Loxahatchee River.

In addition, Cypress Creek/Pal-Mar and the Groves are two subbasins in the northern area of the Loxahatchee River Watershed. Cypress Creek and Hobe Grove Ditch are important sources of surface water flow to the Northwest Fork. The Martin County, SFWMD, Florida Fish and Wildlife Conservation Commission (FWC), FDEP, and Palm Beach County have teamed together, using funds from Martin County, the SFWMD and state appropriations through the LRPI to study these areas. Through Phase I of the study the following water resource related problems have been identified:

1. Upstream movement of salt water in the Northwest Fork of the Loxahatchee River
2. Sediment loading in Cypress Creek and the Northwest Fork of the Loxahatchee River
3. Flooding in Ranch Colony during severe storms
4. Over drainage in the Pal-Mar wetlands.

Phase II of this analysis is underway with a set of models being developed that represent the hydrologic and hydraulic processes in Cypress Creek/Pal-Mar and the Groves basins. The models will provide a basis for solutions to the current problems of the area, such as, means to improve wetland management on the Pal-Mar property and to identify and manage discharge volumes from the Groves and from Cypress Creek to the Northwest Fork of the Loxahatchee River. Coordination with the SFWMD on the NPBC, Part 1 CERP Project studies is taking place to cost-share and increase information on this part of the Northwest Fork Watershed. Both Martin County and Palm Beach County are represented on the LRMCC.

Local Municipalities

The City of West Palm Beach owns and manages the Grassy Waters Preserve/West Palm Beach Water Catchment Area to provide for urban water supply and to protect the environmental resources of the 20 square mile area. The City is a partner with the SFWMD and other agencies in the development and construction of facilities that will provide historic hydrologic connections between the Grassy Waters Preserve, the Loxahatchee Slough and the Northwest Fork.

The Town of Jupiter has established a stormwater utility to retrofit the stormwater systems within the incorporated limits of the Town. Through local commitments and state appropriations older systems are being replaced with facilities that will improve drainage and at the same improve the quality of the water entering the Loxahatchee River.

The Town of Jupiter and the Village of Tequesta are located in the immediate watershed of the Loxahatchee River and therefore are represented on the LRMCC.

South Indian River Water Control District

The South Indian River Water Control District (SIRWCD) serves the Jupiter Farms area, which is approximately 10,315 acres in size and drains primarily to the Northwest Fork. Through a partnership with the SFWMD and state appropriations through the LRPI control structures have been installed that provide improved control of discharges from the SIRWCD system to the Northwest Fork. The SIRWCD will continue to participate in projects that will improve and protect the Northwest Fork through participation on the LRMCC and the LRPI committee.

Jupiter Inlet District

Jupiter Inlet District (JID) has developed a Management Plan that outlines their role in the management of the Loxahatchee River. This plan is intended to continue public recreational uses, improve the productivity of the river, and preserve and enhance the natural resources and multiple uses of the Loxahatchee River for which JID has authority (JID 1993). The plan addresses the portion of the Loxahatchee River west of the F.E.C. Railroad trestle including the Central Embayment, North Fork, Northwest Fork, Southwest Fork, C-18 Canal downstream of the S-46 Structure, and minor tributaries. Thirty prioritized options were included in the plan. Specific actions that have been taken include the restoration of four oxbows in the Northwest Fork to preserve natural hydrological functions, an environmental enhancement project for Sim's Creek, and seagrass bed monitoring. The Jupiter Inlet District is a member of the LRMCC and the LRPI committee.

Treasure Coast Regional Planning Council

The Treasure Coast Regional Planning Council (TCRPC) provides a regional forum where elected and appointed leaders regularly come together to discuss complex regional issues; develop strategic regional responses for resolving them; and build consensus for setting and accomplishing regional goals. The Council provides an effective forum to assist the state and local governments in guiding land use and development activities. Elected officials serve annual terms, and gubernatorial appointees serve three-year terms. TCRPC is made up of nineteen elected officials and nine gubernatorial appointees. The mission of the TCRPC is to encourage and enable local units of government and citizenry to assemble and cooperate with one another and with representatives of major economic interests, to promote health, safety, and general welfare of the citizenry, and to plan for future development of the Region that will keep it competitive and afford a high quality of life.

In 1994, the TCRPC recognized the importance of protecting the remaining wetland resources in the Loxahatchee River Watershed and initiated the Loxahatchee River Basin Wetland Planning Project (Treasure Coast Regional Planning Council 1999) to identify wetlands in the Loxahatchee River Watershed and provide information about the functions and values of these wetlands. The TCRPC is represented on the LRMCC.

Florida Inland Navigational District

The Florida Inland Navigational District (FIND) is a state entity that works in cooperation with federal programs to maintain public waterways. FIND has played an important role in funding dredging projects in the Loxahatchee Estuary.

United States Department of Interior, Fish and Wildlife Service

In May 1985, the largely pristine portion of the Northwest Fork of the Loxahatchee River was designated by the U.S. Department of the Interior, Fish and Wildlife Service (USDOI/FWS) for inclusion in the Federal Wild and Scenic Rivers System, following designation by the state of Florida as a Wild and Scenic River in 1983 (Chapter 83-358, Laws of Florida, approved June 1983). The Northwest Fork of the Loxahatchee River was the first river in the state of Florida to receive this designation. USDOI/FWS participates as a member of the LRMCC.

Private and Special Interest Groups

The SFWMD, FDEP and the LRD recognize that the Northwest Fork is important to the residents of the Loxahatchee River Watershed. Therefore, community participation was invited and encouraged in the development of this restoration plan. Community participation is equally important in all the stages of implementation of the plan and is critical to the success of restoration of the Northwest Fork. Members of the Loxahatchee River Environmental Coalition, Friends of the Loxahatchee River, Friends of Jonathan Dickinson State Park, 1000 Friends of Florida and the Florida Audubon Society participated in the many public meetings during the development of the plan, The active interest and continued participation of these community groups and others nongovernmental organizations (NGOs) is critical to the success of the implementation of the plans, projects and programs designed to restore the Northwest Fork of the Loxahatchee River.